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WE PRESENT this Manual of the American Steel & Wire Company's Process of Water Purification in briefest form consistent with a fair treatment of the essential features, and because of the emergency which has suddenly arisen in the chemical world on account of prevailing foreign conditions.

These conditions seriously affect the operation of water purification plants employing other chemicals, while those using Sulphate of Iron are not affected.

We endeavor to set forth the formula of the Sulphate of Iron Process in advance of further data which may develop, and solicit inquiries on the subject with statement of water conditions upon which we will give the expert advice of our Engineering Bureau of Water Purification.

American Steel & Wire Company

January, 1916

PAGE

Chemical Formulas, see Table No. 5.
Chemical Impurities in Treatment 98
Chemical Substances, Names, Formulas and Weights 113
Chemical Treatment, Where Applied 14
Chemical Treatment, How Applied 14
Chemical Treatment, Difficulties Involved in 14
Chemical Treatment, Success of . . 14
Chemical Treatment, Demands for 14
Chemical Treatment for Turbidity 96
Chemical Treatment for Color . . 96
Chemical Treatment for Bacteria . 96
Chemical Treatment, Point of Application 47
Chemical Treatment, Sulphate of Iron 47
Chemical Treatment, Caustic Lime 47
Chemical Treatment, Errors in . . 46
Chemical Treatment, Wastefulness in Fixed Rate 46
Chemical Treatment, Inaccuracy of Fixed Rate 46
Chemical Treatment, Formulas for 43
Chemical Treatment, to Determine 43
Chemical Treatment, Pounds Required 43
Chemical Treatment, Grains per Gallon Required 44
Chemical Treatment, Rule for Use of Iron Sulphate 99–102
Chemical Treatment, Rule for Use of Caustic Lime 99–102
Chemical Treatment, Size of Orifice Required 44
Chemical Treatment, with Calcium Oxide 96
Chemical Treatment, with Calcium Hydrate 96
Chemical Treatment, with Sodium Carbonate 96
Chemical Treatment, with Sodium Hydrate 96
Chemical Treatment, with Sodium Oxide 96
Chemical Treatment, Influenced by Plant Construction 99
Chemical Treatment, Factors for Aluminum Sulphate 135
Chemical Treatment, Factors for Barium Oxide 135

PAGE

Chemical Treatment, Factors for Calcium Hydrate 136
Chemical Treatment, Factors for Calcium Oxide 135
Chemical Treatment, Factors for Calcium Monocarbonate . . . 136
Chemica Treatment, Factors for Calcium Bicarbonate 136
Chemical Treatment, Factors for Iron Sulphate 136
Chemical Treatment, Factors for Magnesium Oxide 136
Chemical Treatment, Factors for Magnesium Hydrate 137
Chemical Treatment, Factors for Magnesium Monocarbonate . 137
Chemical Treatment Factors for Magnesium Bicarbonate . . 137
Chemical Treatment, Factors for Magnesium Chloride 137
Chemica Treatment, Factors for Magnesium Sulphate 137
Chemical Treatment, Factors for Sodium Oxide 137
Chemical Treatment, Factors for Sodium Hydrate 137
Chemical Treatment, Factors for Sodium Monocarbonate . . . 137
Chemical Treatment, Factors for Substances Remaining in Solution 138
Chemical Treatment, Factors for Sulphuric Anhydride 138
Chemical Treatment, Factors for Sulphuric Acid 138
Chemical Reactions, Use of 120
Chemical Reactions of Aluminum Compounds 114
Chemical Reactions of Barium Compounds 115
Chemical Reactions of Calcium Compounds 115
Chemical Reactions of Carbonic Acid 116
Chemical Reactions of Copper Compounds 117
Chemical Reactions of Iron Sulphate 117
Chemical Reactions of Magnesium Compounds 117
Chemical Reactions of Sodium Compounds 118

PAGE

Chemical Reactions of Sulphuric Acid 120
Chemical Wastage in Treatment. . 98
Chemical Weight Table 113
Chloride Hardness, Defined 151
Chlorine Compounds, Factors for . 125
Circular Orifices, Discharge 25
Circular Orifices, Diameters 25
Circular Orifices, Areas 25
Circular Orifices, Factors 24–33
Clarification and Purification . . . 99
Clarification and Purification, Rule for Chemical Treatment . 99–102
Clarification and Purification, Rule for Use of Iron Sulphate . . 99–102
Clarification and Purification, Rule for Use of Caustic Lime . . 99–102
Coagulation, by Sulphate of Iron, Rule for 99–102
Coagulation, by Caustic Lime, Rule for 99–102
Coagulation, by Soda Ash 102
Coagulation, by Sodium Carbonate 102
Coagulation, Forming 56
Coagulation, Size of 56
Coagulation, Quality of 56
Coagulation, Test for 56
Coagulation, Breaking up 60
Color of Water 75–84
Color of Water, to Determine . . 75–83
Color of Water, Standard 81–82
Computing Chemical Equations . . 120
Constant Head Device for Lime . . 51
Constant Rate Filter Controller . . 70
Constant Rate Filter Controller, Function of 70
Control for End Point in Chemical Work 91
Controllers, Filter Constant Rate . 70
Controllers, Function of 70
Controllers, Imperfections of Early Types 71
Controllers, Over-running 71
Controllers, Breaking Beds 71
Controllers, Bacterial Inefficiency due to 71
Controllers, Newer Types 72
Controllers, Functions of 72
Controllers, Objections to 72
Controllers, Variable Rate 72

PAGE

Controllers, Functions of 73
Controllers, Advantages over Fixed Rate Type 73
Controllers, Economy of Variable Rate Type 72
Controllers, Filter, Increased Capacity of Filter due to . . . 73–74
Controllers, Filter, Increased Capacity of Clear Well due to . 73
Controllers, Filter and Chemical, Meter Type 74
Controllers, Filter and Chemical, Meter Type, Advantages . . . 74
Controllers, Filter and Chemical, Meter Type, Economy 74
Co-operation to Prevent Disease . . 8
Copper Chloride, Chemical Formula 113
Copper Chloride, Chemical Weight 113
Copper Compounds, Factors for . . 124
Copper Hydrate, Chemical Formula 113
Copper Hydrate, Chemical Weight 113
Copper Oxide, Chemical Formula . 113
Copper Oxide, Chemical Weight . 113
Copper Sulphate, Chemical Formula 113
Copper Sulphate, Chemical Weight 113
Copper Sulphate, Equivalents of . 133
Core, Lump Lime, Containing . . . 47
Cubic Centimeter, Equivalents of . 153
Cubic Inch, Equivalents of 153
Cubic Foot, Equivalents of 153
Cubic Yard, Equivalents 153
Cubic Millimeter, Equivalents . . 153
Cubic Meter, Equivalents 153
Cupric Sulphate, Equivalents . . . 133

Decagram Equivalents 153
Decaliter Equivalents 153
Deciliter Equivalents 153
Decameter Equivalents 153
Decatonne Equivalents 153
Decastere Equivalents 153
Decimeter Equivalents 153
Decistere Equivalents 153
Determinations of Discharge . . . 24
Determinations of Velocity of Flow 32
Determinations of Velocity of Flow, Factor 32
Determinations of Gallons Discharged 32

PAGE

Determinations of Diameters of Pipes or Orifices 32
Determination of Chemical Discharge 43
Determination of Pumpage 43
Determination of Grains per Gallon of Chemicals 44
Determination of Size of Orifice . . 44
Determination of Coefficient of Discharge 45
Determination of Depth of Sludge . 62
Determination of Proper Coagulation 56
Determination of Turbidity . . . 75–81
Determination of Color 81–84
Determination of Free Carbonic Acid 84
Determination of Alkalinity, Caustic 89–92
Determination of Alkalinity, Monocarbonate 93
Determination of Alkalinity, Bicarbonate 93
Determination of Alkalinity, Caustic and Monocarbonate . . . 94
Determination of Alkalinity, Mono and Bicarbonate 94
Determination of Alkalinity, Bicarbonate and Free Carbonic Acid 95
Determination of Alkalinity, Total 94–95
Determination of Alkalinity, Treatments 96
Determination of Bacterial Count 105–108
Determination of Chemical Quantities 120
Disease, Responsibility for 7
Disease, Water Borne 7
Disease, Kills Civilization 7
Disease, Early History, Epidemics, and Pestilences 7
Disease, Cause of, and Co-operation to Prevent 8
Disease, Ignorance Causes, Knowledge Prevents 8
Disease, Effects on Progeny . . . 8
Disease, Cost of 9
Disease, Breeds Ignorance 10
Displacement Factors for Aluminum Sulphate 135

PAGE

Displacement Factors for Barium Oxide 135
Displacement Factors for Calcium Oxide 135
Displacement Factors for Calcium Hydrate 136
Displacement Factors for Calcium Monocarbonate 136
Displacement Factors for Calcium Bicarbonate 136
Displacement Factors for Iron Sulphate 136
Displacement Factors for Magnesium Oxide 136
Displacement Factors for Magnesium Hydrate 137
Displacement Factors for Magnesium Monocarbonate . . . 137
Displacement Factors for Magnesium Bicarbonate 137
Displacement Factors for Magnesium Chloride 137
Displacement Factors for Magnesium Sulphate 137
Displacement Factors for Sodium Oxide 137
Displacement Factors for Sodium Hydrate 137
Displacement Factors for Sodium Monocarbonate 137
Displacement Factors for Sulphuric Anhydride 138
Displacement Factors for Sulphuric Acid 138
Distributing Weir in Settling Basins 60

Earl Type Variable Rate Filter Controller 73
Earl Type Variable Rate Chemical Controller 46
Effective Size of Sand 75
Effective Size of Sand 65–66
Effective Size of Sand 95
End Point of Indicators 89
End Point of Methyl Orange . . . 91
End Point of Methyl Orange Detecting 91
End Point, Use of Control 91
Engineering Bureau Services . . 5–6–102

PAGE

Engineering Bureau, Function of . 5
Epidemics, Ancient 7
Equivalents, Tables of Factors 123–128
Equivalents, Tables of Alkalinities 129–130
Equivalents, Tables of Hardness 131–134
Equivalents, Tables of Incompatibles 135–138
Equivalents, Tables of Treatments 96–135–138
Equivalents, Tables of Heads and Pressures 34–40
Equivalents, on Analysis Form . . 150
Equivalent Pressures under Varying Heads 34–40
Example of Chemical Computation 120
Exceptions to Rule for Use 102
Explanations of Terms on Analysis Form 151

Factors for Aluminum Compounds 123
Factors for Barium Compounds . . 124
Factors for Calcium Compounds . 124
Factors for Carbonic Acid Compounds 124
Factors for Copper Compounds . . 124
Factors for Chlorine Compounds . 125
Factors for Iron Compounds . . . 125
Factors for Magnesium Compounds 126
Factors for Sodium Compounds . . 126
Factors for Sulphuric Acid Compounds 127
Factors for Alkalinity Equivalents of Calcium Oxide 129
Factors for Alkalinity Equivalents of Calcium Hydrate 129
Factors for Alkalinity Equivalents of Calcium Monocarbonate . . 129
Factors for Alkalinity Equivalents of Calcium Bicarbonate . . . 129
Factors for Alkalinity Equivalents of Magnesium Oxide 129
Factors for Alkalinity Equivalents of Magnesium Hydrate . . . 129
Factors for Alkalinity Equivalents of Magnesium Monocarbonate 130
Factors for Alkalinity Equivalents of Magnesium Bicarbonate . . 130
Factors for Alkalinity Equivalents *of Sodium* Oxide 130

PAGE

Factors for Alkalinity Equivalents of Sodium Hydrate 130
Factors for Alkalinity Equivalents of Sodium Monocarbonate . . 130
Factors for Chemical Treatment of Aluminum Sulphate 135
Factors for Chemical Treatment of Barium Oxide 135
Factors for Chemical Treatment of Calcium Oxide 135
Factors for Chemical Treatment of Calcium Hydrate 136
Factors for Chemical Treatment of Calcium Monocarbonate . . . 136
Factors for Chemical Treatment of Calcium Bicarbonate 136
Factors for Chemical Treatment of Iron Sulphate 136
Factors for Chemical Treatment of Magnesium Oxide 136
Factors for Chemical Treatment of Magnesium Hydrate 137
Factors for Chemical Treatment of Magnesium Monocarbonate . . 137
Factors for Chemical Treatment of Magnesium Bicarbonate . . . 137
Factors for Chemical Treatment of Magnesium Chloride 137
Factors for Chemical Treatment of Magnesium Sulphate 137
Factors for Chemical Treatment of Sodium Oxide 137
Factors for Chemical Treatment of Sodium Hydrate 137
Factors for Chemical Treatment of Sodium Monocarbonate . . . 137
Factors for Chemical Treatment of Sulphuric Anhydride 138
Factors for Chemical Treatment of Sulphuric Acid 138
Factors for Hardness Equivalents of Aluminum Sulphate 131
Factors for Hardness Equivalents of Calcium Oxide 131
Factors for Hardness Equivalents of Calcium Hydrate 131
Factors for Hardness Equivalents of Calcium Monocarbonate . . . 131
Factors for Hardness Equivalents of Calcium Bicarbonate 132

	Page
Factors for Hardness Equivalents of Calcium Chloride	132
Factors for Hardness Equivalents of Calcium Sulphate	132
Factors for Hardness Equivalents of Carbonic Acid	132
Factors for Hardness Equivalents of Copper Sulphate	133
Factors for Hardness Equivalents of Iron Sulphate	133
Factors for Hardness Equivalents of Magnesium Oxide	133
Factors for Hardness Equivalents of Magnesium Hydrate	133
Factors for Hardness Equivalents of Magnesium Monocarbonate	134
Factors for Hardness Equivalents of Magnesium Bicarbonate	134
Factors for Hardness Equivalents of Magnesium Chloride	134
Factors for Hardness Equivalents of Magnesium Sulphate	134
Factors for Incompatible Equivalents of Aluminum Sulphate	135
Factors for Incompatible Equivalents of Barium Oxide	135
Factors for Incompatible Equivalents of Calcium Oxide	135
Factors for Incompatible Equivalents of Calcium Hydrate	136
Factors for Incompatible Equivalents of Calcium Monocarbonate	136
Factors of Incompatible Equivalents of Calcium Bicarbonate	136
Factors for Incompatible Equivalents of Iron Sulphate	136
Factors for Incompatible Equivalents of Magnesium Oxide	136
Factors for Incompatible Equivalents of Magnesium Hydrate	137
Factors for Incompatible Equivalents of Magnesium Monocarbonate	137
Factors for Incompatible Equivalents of Magnesium Bicarbonate	137
Factors for Incompatible Equivalents of Magnesium Chloride	137
Factors for Incompatible Equivalents of Magnesium Sulphate	137
Factors for Incompatible Equivalents of Sodium Oxide	137
Factors for Incompatible Equivalents of Sodium Hydrate	137
Factors for Incompatible Equivalents of Sodium Monocarbonate	137
Factors for Incompatible Equivalents of Sulphuric Anhydride	138
Factors for Incompatible Equivalents of Sulphuric Acid	138
Fargo Mixing Chamber, Requirements	53
Filters, Sand Beds of	66
Filters, Bottoms	66
Filters, Neccessity for Good Filters	64
Filters, Design of	64
Filters, Cleaning	64
Filters, Experimental	64
Filters, Suspended Matter	65
Filters, Size of Sand	65
Filters, Rate of Filtration	65
Filters, Air Wash	64
Filters, Length of Run	66
Filters, Wash Troughs	66
Filter Controllers, Variable Rate	72
Filter Controllers, Function of	73
Filter Controllers, Advantages over Fixed Rate Controllers	73
Filter Controllers, Economy of	72
Filter Controllers, Increased Capacity of Filters due to	73
Filter Controllers, Increased Capacity of Clear Well due to	74
Filter Controllers, Meter Controller	74
Filter Controllers, Meter Controller, Advantages of	74
Filter Controllers, Meter Controller, Economy of	74
Filter Controllers, Fixed Rate	70
Filter Controllers, Fixed Rate, Function of	70
Filter Controllers, Fixed Rate, Imperfections of Early Type	71
Filter Controllers, Fixed Rate, Overrunning	71
Filter Controllers, Fixed Rate, Breaking Beds	71
Filter Controllers, Fixed Rate, Bacterial Inefficiency due to	71
Filter Controllers, Fixed Rate, Newer Type	72
Filter Controllers, Fixed Rate, Newer Type, Function of	72

PAGE

Filter Controllers, Fixed Rate, Newer Type, Objections to . . 72
Filter Manifold for Water 68
Filtration without Softening . . . 99
Filtration, Rule for Chemical Treatment 99–102
Fixed Alkali Bicarbonates, Defined 151
Fixed Alkali Carbonates, Defined . 151
Fixed Alkali Caustics, Defined . . 151
Fixed Alkali Monocarbonates, Defined 151
Fixed Rate Filter Controllers . . . 70
Fixed Rate Filter Controllers, Function of 70
Fixed Rate Head Tank for Lime . . 51
Foot Equivalents 153
Formula for Chemical Charges . . 43
Formula for Pumpage 43
Formula for Grains per Gallon Treatment 44
Formula for Calibrating Orifices . . 45
Free Acid Hardness, Defined . . . 151
Free Carbonic Acid Incompatibles 136–148
Free Carbonic Acid, to Treat . . . 96
Free Carbonic Acid, to Determine . 84
Free Mineral Acid, to Treat . . . 95
Free Sulphuric Acid Incompatibles 138–147
Furlong Equivalents 153

Gallon Equivalents 153
Gelatine Count, Importance of . . 105
General Chemistry of Water . . . 104
Gill Equivalents 153
Grain Equivalents 153
Grains per Gallon, Explained . . . 122
Grains per Gallon, Conversion to Parts per Million 122–145
Grains per Gallon, Conversion to Pounds per Million 145
Gram Equivalents 153
Gravel in Filters 66

Hardness, Defined 151
Hardening Compounds in Water . . 110
Hardness Equivalents of Aluminum Sulphate 131
Hardness Equivalents of Calcium Oxide 131

PAG

Hardness Equivalents of Calcium Hydrate 13
Hardness Equivalents of Calcium Monocarbonate 13
Hardness Equivalents of Calcium Bicarbonate 13
Hardness Equivalents of Calcium Chloride 13
Hardness Equivalents of Calcium Sulphate 13
Hardness Equivalents of Carbonic Acid 13
Hardness Equivalents of Cupric Sulphate 13
Hardness Equivalents of Iron Sulphate 13
Hardness Equivalents of Magnesium Oxide 13
Hardness Equivalents of Magnesium Hydrate 13
Hardness Equivalents of Magnesium Monocarbonate 13
Hardness Equivalents of Magnesium Bicarbonate 13
Hardness Equivalents of Magnesium Chloride 13
Hardness Equivalents of Magnesium Sulphate 13
Hardness Equivalents on Analysis Form 15
Hard Spots in Filters 6
Hard Water Defined 11
Head Tanks for Lime 5
Head Tanks for Constant Rate Chemical Feed Device 5
Hectare Equivalents 15
Hectogram Equivalents 15
Hectoliter Equivalents 15
Hectometer Equivalents 15
Hogshead Equivalents 15
Hook Gauge for Drop in Level . . 4
How to Use American Steel & Wire Co.'s Process 9
Hydrated Lime, Commercial Product. 4
Hydrated Lime, Magnesia in . . . 4
Hydrated Lime, Requirements . . 4
Hydrated Lime, Loss of 4
Hydrated Lime, Solubility 4
Hydrated Lime, Milk of 4

PAGE

Hydrated Lime, Metals Used to Handle 49
Hydrated Lime, Suspension of . . . 49
Hydrated Lime, Agitating Suspensions of 49
Hydrochloric Acid, Chemical Formula 113
Hydrochloric Acid, Chemical Weight 113

Importance of Gelatine Count 105–106
Impractical Treatment Table . . . 96
Improved Odor by Iron Sulphate . 144
Improved Taste by Iron Sulphate . 144
Impure Water, Danger of 10
Impure Water, Responsibility for . 10
Impure Water, No Necessity for . 10
Impure Water can be Purified . . 10
Impure Water should not be Tolerated 11
Inch Equivalents 153
Incompatibles on Analysis Form 147–148
Incompatible Equivalents of Aluminum Sulphate 135
Incompatible Equivalents of Barium Oxide 135
Incompatible Equivalents of Calcium Oxide 135
Incompatible Equivalents of Calcium Hydrate 136–147
Incompatible Equivalents of Calcium Monocarbonate . . 136–147
Incompatible Equivalents of Calcium Bicarbonate 136–147
Incompatible Equivalents of Calcium Chloride 136–148
Incompatible Equivalents of Calcium Sulphate 136–148
Incompatible Equivalents of Free Carbonic Acid 136–148
Incompatible Equivalents of Iron Sulphate 136
Incompatible Equivalents of Magnesium Oxide 136
Incompatible Equivalents of Magnesium Hydrate 137
Incompatible Equivalents of Magnesium Monocarbonate 137
Incompatible Equivalents of Magnesium Bicarbonate 137

PAGE

Incompatible Equivalents of Magnesium Chloride 137–148
Incompatible Equivalents of Magnesium Sulphate 137–148
Incompatible Equivalents of Sodium Oxide 137
Incompatible Equivalents of Sodium Hydrate 137–147
Incompatible Equivalents of Sodium Monocarbonate 137–148
Incompatible Equivalents of Sodium Bicarbonate 148
Incompatible Equivalents of Sulphuric Anhydride 138
Incompatible Equivalents of Sulphuric Acid 138–147
Incrustation Due to Lime 47
Incrustation in Softening 100
Indicators, Chemical 86
Iron Carbonate, Chemical Formula 113
Iron Carbonate, Chemical Weight . 113
Iron Chloride, Chemical Formula . 113
Iron Chloride, Chemical Weight . 113
Iron Compounds, Factors for . . . 125
Iron Hydrate, Chemical Formula . 113
Iron Hydrate, Chemical Weight . . 113
Iron Oxide, Chemical Formula . . 113
Iron Oxide, Chemical Weight . . . 113
Iron Sulphate, Chemical Formula . 113
Iron Sulphate, Chemical Weight . . 113
Iron Sulphate Equivalents 133
Iron Sulphate, How to Use 99
Iron Sulphate Incompatibles . . . 136

Kilogram Equivalents 153
Kiloliter Equivalents 153
Kilometer Equivalents 153

League Equivalents 153
Length of Run of Filters 65–66
Lime, Use of, in Treating Water . . 99
Lime, Rule for Use 99
Lime, Testing for Proper Usage . 99
Lime, Loss of 48
Lime, Strength 48
Lime, Solubility 48
Lime, Milk of 49
Lime, Agitating 49
Lime, Metals to Handle 49

PAGE

Lime Head Tank or Constant Head Device 51
Linear Equivalents 153
Liter Equivalents 153
Litmus for Testing 87
Lump Lime, Commercial Product . 47
Lump Lime, Core 47
Lump Lime, Requirements 47
Lump Lime, Slaking 48
Lump Lime, Loss of 48
Lump Lime, Solubility 48
Lump Lime, Milk of 49
Lump Lime, Metal to Handle . . . 49

Magnesium Bicarbonate, Chemical Formula 113
Magnesium Bicarbonate, Chemical Weight 113
Magnesium Bicarbonate Equivalents 130–134
Magnesium Bicarbonate Incompatibles 137
Magnesium Chloride, Chemical Formula 113
Magnesium Chloride, Chemical Weight 113
Magnesium Chloride Equivalents . 134
Magnesium Chloride Incompatibles 137–147
Magnesium Compounds, Factors for 126
Magnesium Hydrate, Chemical Formula 113
Magnesium Hydrate, Chemical Weight 113
Magnesium Hydrate Equivalents 129–133
Magnesium Hydrate Incompatibles 136
Magnesium Monocarbonate, Chemical Formula 113
Magnesium Monocarbonate, Chemical Weight 113
Magnesium Monocarbonate Equivalents 130–134
Magnesium Monocarbonate Incompatibles 136
Magnesium Nitrate, Chemical Formula 113
Magnesium Nitrate, Chemical Weight 113
Magnesium Oxide, Chemical Formula 113

PAGE

Magnesium Oxide, Chemical Weight 113
Magnesium Oxide Equivalents . 129–133
Magnesium Oxide Incompatibles . 136
Magnesium (Tri-Magnesic) Phosphate, Chemical Formula . . 113
Magnesium (Tri-Magnesic) Phosphate, Chemical Weight . . . 113
Magnesium Pyrophosphate, Chemical Formula 113
Magnesium Pyrophosphate, Chemical Weight 113
Magnesium Sulphate, Chemical Formula 113
Magnesium Sulphate, Chemical Weight 113
Magnesium Sulphate Equivalents . 134
Magnesium Sulphate Incompatibles 137–148
Mass Equivalents 153
Mechanical Filtration, Early Results 11
Mechanical Filtration, Progress . . 11
Mechanical Filtration, Chemical Methods 11
Meter Equivalents 153
Meter Filter Controllers 74
Meter Filter Controllers Save Wash Water 74
Meter Filter Controllers Indicate Filter Troubles 74
Meter Filter Controllers Indicate Filter Inefficiencies 74
Metering Flow of Chemicals by Chemical Controller 74
Meter Flow of Water by Filter Controller 74
Methods of Using American Steel and Wire Co.'s Process 99
Methyl Orange Indicator 88
Mile Equivalents 153
Milk of Lime, Preparation 49
Milk of Lime, Strength 49
Milk of Lime, Agitating 49
Milk of Lime, Metals to Handle . . 49
Millier Equivalents 153
Milligram Equivalents 153
Milliliter Equivalents 153
Millimeter Equivalents 153
Miniature U. S. Gallon, Defined . . 122
Mineral Matter in Relation to Health 110
Mixing Chambers, Types 53
Mixing Chambers, Function . . . 53

	Page
Mixing Chambers, Requirements	53
Mixing Chambers, Efficiencies	59
Mixing Chambers, Economy of Chemicals	59
Mixing Chambers, Capacity	53
Monocarbonate Alkalinity Defined	151
Monocarbonate Alkalinity, to Treat	96
Monocarbonate Alkalinity, Conversion to Bicarbonate	90
Monocarbonate Alkalinity, Conversion to Sulphate Hardness	90
Monocarbonate Alkalinity Determination	93
Monocarbonate Aklalinity Limitations	86
Monocarbonate and Bicarbonate Alkalinity Determination	94
Monocarbonate Hardness Defined	151
Moral Tone Lowered by Disease	8
Mortality in United States	8
Myriameter Equivalents	153
Myriogram Equivalents	153
Myrioliter Equivalents	153
Neutral Water Defined	87
Neutral Water Test	87
Neutralization Factors for Aluminum Sulphate	135
Neutralization Factors for Barium Oxide	135
Neutralization Factors for Calcium Oxide	135
Neutralization Factors for Calcium Hydrate	136
Neutralization Factors for Calcium Monocarbonate	136
Neutralization Factors for Calcium Bicarbonate	136
Neutralization Factors for Calcium Chloride	136
Neutralization Factors for Calcium Sulphate	136
Neutralization Factors for Iron Sulphate	136
Neutralization Factors for Magnesium Oxide	136
Neutralization Factors for Magnesium Hydrate	137
Neutralization Factors for Magnesium Monocarbonate	137
Neutralization Factors for Magnesium Bicarbonate	137
Neutralization Factors for Magnesium Chloride	137
Neutralization Factors for Magnesium Sulphate	137
Neutralization Factors for Sodium Oxide	137
Neutralization Factors for Sodium Hydrate	137
Neutralization Factors for Sodium Monocarbonate	137
Neutralization Factors for Sulphuric Anhydride	138
Neutralization Factors for Sulphuric Acid	138
Neutralization Values on Analysis Form	149
New Orleans Mixing Chamber	53
Normal Carbonate Alkalinity	75
Normal Carbonate Alkalinity Limitations	86
Normal Twenty-Secondth Sodium Carbonate Solution	85
Normal Fiftieth Sulphuric Acid Solution	89
Normal Fiftieth Sulphuric Acid Solution, Equivalent	90
Odor Improved by Use of Sulphate of Iron	144
Oil Barrel Equivalents	153
Operating Guide, Gelatin Count	106
Organic Matters in Water	104
Orifices, Diameters, Areas, and Discharges	25 to 31
Orifices, Factors for	24–33
Ounce Equivalents	153
Overrunning of Filter Controllers	71
Parts per Million Explained	121
Parts per Million Converted	121
Parts per Million, Conversion	96–121–122–145
Phosphorus Pentoxide, Chemical Formula	113
Phosphorus Pentoxide, Chemical Weight	113
Pint Equivalents	153

	PAGE
Phenolphthaleine Test Solution or Indicator Solution	85
Phenolphthaleine Test Solution, Misuse of	89
Pipes, Velocity of Flow Through	31
Pipes, Diameter of	32
Pipes, Discharge Through	32
Pipes, Factor for Formula	32
Plant Construction Influences Chemical Treatment	99
Planting Bacterial Samples	108
Planting Bacterial Samples, Precautions	109
Planting Bacterial Samples, Control	110
Plant Operation, Data for	75
Pound Equivalents	153
Precautions in Taking and Handling Bacterial Samples	108
Precipitation Factors for Aluminum Sulphate	135
Precipitation Factors for Barium Oxide	135
Precipitation Factors for Iron Sulphate	136
Prevention of Disease,	9
Prevention of Disease, Effects of	9
Prostitution Caused by Disease	8
Pumps, Low Service	13
Quart Equivalents	153
Quick Lime, Commercial Product	47
Quick Lime, Requirements	47
Quick Lime, Slaking	48
Quick Lime, Loss of	48
Quick Lime, Solubility	48
Quick Lime, Milk of	49
Quick Lime, Metals to Handle	49
Quick Lime, Homogeneous Suspension of	49
Quintal Equivalents	153
Reactions of Aluminum Compounds	114
Reactions of Barium Compounds	115
Reactions of Calcium Compounds	115
Reactions of Carbonic Acid Compounds	116
Reactions of Copper Compounds	117
Reactions of Iron Sulphate	117
Reactions of Magnesium Compounds	117
Reactions of Sodium Compounds	118
Reactions of Sulphuric Acid Compounds	120
Rate of Filtration	.73 to 75
Rate of Filtration, Past and Present	65
Raw Water, Recording Flow of	46
Red Water Defined	140
Red Water, Effects on Linen, and Fixtures	140
Red Water, Destruction of Mains and Services	141
Red Water Causes Water to be Wasted	141
Red Water, Cause of	141
Red Water, Cure for	142
Red Water, Reactions Explaining	142
Removing Odor	144
Removing Taste	144
Replacement Factors for Aluminum Sulphate	135
Replacement Factors for Barium Oxide	135
Replacement Factors for Calcium Oxide	135
Replacement Factors for Calcium Hydrate	136
Replacement Factors for Calcium Monocarbonate	136
Replacement Factors for Calcium Bicarbonate	136
Replacement Factors for Calcium Chloride	136
Replacement Factors for Calcium Sulphate	136
Replacement Factors for Iron Sulphate	136
Replacement Factors for Magnesium Oxide	136
Replacement Factors for Magnesium Hydrate	137
Replacement Factors for Magnesium Monocarbonate	137
Replacement Factors for Magnesium Bicarbonate	137
Replacement Factors for Magnesium Chloride	137
Replacement Factors for Magnesium Sulphate	137

	Page
Replacement Factors for Sodium Oxide	137
Replacement Factors for Sodium Hydrate	137
Replacement Factors for Sodium Monocarbonate	137
Replacement Factors for Sulphuric Anhydride	138
Replacement Factors for Sulphuric Acid	138
Responsibility for Disease	8
Responsibility of Public Officials	7
Responsibility for Human Life	8
Responsibility, Purpose of	9
Rod Equivalents	153
Rood Equivalents	153
Rules for Chemical Treatment with Lime	99–102
Rules for Chemical Treatment with Iron	99–102
Sand Beds in Filters	66
Sand Catchers	66
Sand, Effective Size	66
Scale Forming Substances	110
Settling Basins, Capacity in Hours	95
Settling Basins, Cleaning	60
Settling Basins, Cross Section Flow Through	60
Settling Basins, Collecting Weir, or Skimming Weir	60
Settling Basins, Distributing Weir	60
Settling Basins, Diverted Flow	60
Settling Basins, Efficiency of	59
Settling Basins, Efficiency of, Increased by Mixing Chamber	56
Settling Basins, Experimental	62
Settling Basins, Function of	59
Settling Basins, Observation of	62
Settling Basins, Requirements	60
Settling Basins Saves Wash Water	59
Settling Basins, Sludge Zone	60
Settling Basins, Straight Flow	60
Settling Basins, Successful	60
Settling Basins, Surface Flow	60
Settling Basins, Testing Sludge Zone	62
Settling Basins, Water Enters	56
Settling Basins, Water Leaves	60
Silicon Dioxide, Chemical Formula	114
Silicon Dioxide, Chemical Weight	114
Silver Nitrate Test for Caustic Alkalinity	89
Skimming Weir in Settling Basin	60
Slaking Lump Lime	48
Slaking Loss	48
Sludge Zone Test in Settling Basins	62
Sodium Bicarbonate, Chemical Formula	114
Sodium Bicarbonate, Chemical Weight	114
Sodium Bicarbonate Incompatibles	148
Sodium Carbonate Volumetric Solution, N/22	85
Sodium Chloride, Chemical Formula	114
Sodium Chloride, Chemical Weight	114
Sodium Compounds, Factors for	126
Sodium Fluoride, Chemical Formula	114
Sodium Fluoride, Chemical Weight	114
Sodium Hydrate, Chemical Formula	114
Sodium Hydrate, Chemical Weight	114
Sodium Hydrate Equivalents	130
Sodium Hydrate Incompatibles	137–147
Sodium Monocarbonate, Chemical Formula	114
Sodium Monocarbonate, Chemical Weight	114
Sodium Monocarbonate Equivalents	130
Sodium Monocarbonate Incompatibles	137–148
Sodium Nitrate, Chemical Formula	114
Sodium Nitrate, Chemical Weight	114
Sodium Nitrite, Chemical Formula	114
Sodium Nitrite, Chemical Weight	114
Sodium Oxide, Chemical Formula	114
Sodium Oxide, Chemical Weight	114
Sodium Oxide Equivalents	130
Sodium Oxide Incompatibles	137
Sodium (Di-Sodic) Phosphate, Chemical Formula	114
Sodium (Di-Sodic) Phosphate, Chemical Weight	114
Sodium (Tri-Sodic) Phosphate, Chemical Formula	114
Sodium (Tri-Sodic) Phosphate, Chemical Weight	114
Sodium Sulphate, Chemical Formula	114
Sodium Sulphate, Chemical Weight	114
Softening Process, Abuse of	103
Softening Process, Advantages	103
Softening Process, Bacterial Efficiencies	103

	PAGE
Softening Process, Cost	103
Softening Process, Drawbacks	100
Softening Process, When not Desirable	104
Softening Process, Objections to	102
Softening Process, Rule for Using	102
Softening Process, Substances Remaining in Solution	138
Standard Methods of Analysis, Criticism of Last Edition	105
Standard Orifices	23
Standard Orifices, Coefficient of Discharge	24
Standard Orifices, Discharge Table for	25
Standard Orifices, Factor for	24
Standard Orifices, Formula of Discharge	24
Stere Equivalents	153
Strainers in Filters	66–68
Substances Producing Alkalinity	150
Substances Producing Hardness	150
Substances Producing Alkalinity and Hardness	150
Substances Producing Neither Alkalinity or Hardness	150
Substances Remaining in Solution as Result of Chemical Treatment	138
Sulphate Hardness Defined	151
Sulphate of Iron, Acid Resisting Metals	19
Sulphate of Iron, Applying	22
Sulphate of Iron, Chemical Orifices for	23
Sulphate of Iron, Chemical Formula	15–113
Sulphate of Iron, Chemical Weight	15–113
Sulphate of Iron, Crystals	15
Sulphate of Iron, Deterioration of	16
Sulphate of Iron, Dissolving	17
Sulphate of Iron, Economy in Purchasing	16
Sulphate of Iron, Fixed Rate Application	22
Sulphate of Iron, Handling	15
Sulphate of Iron, Head Tank	22
Sulphate of Iron, How Shipped	16
Sulphate of Iron, Metals Affected	19
hate of Iron, Pumping Solutions	19
Sulphate of Iron, Size of Packages	16
Sulphate of Iron, Solubility	17
Sulphate of Iron, Standard Orifice for	23
Sulphate of Iron, Stirring Devices for	19
Sulphate of Iron, Stirring Solutions	17
Sulphate of Iron, Strength	15
Sulphate of Iron, Sugar	15
Sulphate of Iron, Unloading	16
Sulphate of Iron, Variable Head over Orifice	23
Sulphate of Iron, Water of Crystallization	15
Sulpho-Cloride Hardness Defined	151
Sulphuric Acid, Chemical Formula	114
Sulphuric Acid, Chemical Weight	114
Sulphuric Acid Compounds, Factors for	127
Sulphuric Acid Incompatibles	138–147
Sulphuric Acid, Normal Fiftieth Solution Equivalent	90
Sulphuric Anhydride, Chemical Formula	114
Sulphuric Anhydride, Chemical Weight	114
Sulphuric Anhydride Incompatibles	138
Superficial Equivalents	153
Suspended Matter in Water to Filters	65
Synthesis, Chemical	122
Tables, No. 1	25
Tables, No. 2	34
Tables, No. 3	41
Tables, No. 4	112
Tables, No. 5	113
Tables of Alkalinity	129–130
Tables of Atomic Weights	112
Tables of Areas of Orifices	25 to 31
Tables of Chemical Weights	113–114
Tables of Cubic Feet	41–42
Tables of Cubic Feet per Second Flow	41–42
Tables of Cubic Feet per Minute Flow	41–42
Tables of Diameters of Orifices	25 to 31
Tables of Discharge Under One Foot Head	25 to 31
Tables of Equivalent Heads, Pressures and Discharges	34 to 40
Tables of Factors	123 to 128

PAGE

Tables of Gallons per Day Flow 25 to 32
Tables of Gallons per Day Flow 34 to 40
Tables of Gallons per Minute Flow 25 to 32
Tables of Gallons per Minute Flow 34 to 40
Tables of Gallons per Second Flow 34 to 40
Tables of Gallons per Second Flow 41–42
Tables of Hardness . . . . 131 to 134
Tables of Heads and Pressures . 34–40
Tables of Incompatibles. . . 135 to 138
Tables of Limitations of Chemical Treatment 95
Tables of Million Gallons and Equivalents in Flow 41–42
Tables of Substances Remaining in Solution 138
Tables of Variable Heads and Discharges through Fixed Orifice 34 to 40
Tables of Velocities of Flow Under Varying Heads . . . . . 34 to 40
Tables of Water Heads, Pressures, Velocities and Flows . . . 34 to 40
Taste Improved by Iron Sulphate . 144
To Compute Chemical Quantities . 120
Tonne Equivalents 153
Total Alkalinity 92
Total Carbonate Hardness 151
Total Hardness 151
Treatment Factors for Aluminum Sulphate 135
Treatment Factors for Barium Oxide 135
Treatment Factors for Calcium Oxide 135
Treatment Factors for Calcium Hydrate 136
Treatment Factors for Calcium Monocarbonate 136
Treatment Factors for Calcium Bicarbonate 136
Treatment Factors for Calcium Chloride 136
Treatment Factors for Calcium Sulphate 136
Treatment Factors for Iron Sulphate 136
Treatment Factors for Magnesium Oxide 136
Treatment Factors for Magnesium Hydrate 137
Treatment Factors for Magnesium Monocarbonate 137

PAGE

Treatment Factors for Magnesium Bicarbonate 137
Treatment Factors for Magnesium Chloride 137
Treatment Factors for Magnesium Sulphate 137
Treatment Factors for Sodium Oxide 137
Treatment Factors for Sodium Hydrate 137
Treatment Factors of Sodium Monocarbonate 137
Treatment Factors for Substances Remaining in Solution 138
Treatment Factors for Sulphuric Anhydride 138
Treatment Factors for Sulphuric Acid 138
Turbidity of Water 75
Turbidity, Character of 75–84
Turbidity, To Determine . . . 75 to 80
Turbidity, Standard 78
Turbidity Rod, Graduations . . . 78
Turbidity Rod, May be Purchased . 84
Typhoid Fever, Caused by 9
Typhoid Fever, Cost of 9
Typhoid Fever, Lives Lost by . . 9
Typhoid Fever, and Other Water Borne Diseases 9

Use of Chemical Factors 122
Use of Chemical Reactions 120
Use of Hydraulic Tables . . . 43 to 45
Unnecessary Loss of Life 10
United States Miniature Gallon . . 122

Value of Human Life 9
Value of Lives Lost 9
Variable Rate Chemical Controllers 46
Variable Rate Chemical Controllers, Function of 46
Variable Rate Filter Controllers . . 72
Variable Rate Filter Controllers, Function of 73
Vegetable Matter 104
Velocities, under Varying Heads and Pressures . . . . . 34 to 40
Volumetric Solutions and Their Use 88

	Page
Water, Chemical Formula and Chemical Weight	114
Water, Free from Chemicals Used	12–13
Water, Low Lift of	13
Water, Hard, Defined	110
Water, Bacteriology	104
Water Borne Diseases	7
Water Heads, Table of Heads, Pressures, Velocities and Discharge	34 to 40
Water, Manifold of Filter	70
Water Purification Prevents Disease	8
Water Purification Lowers Death Rate	8
Water Ways Between Mixing Chamber and Settling Basins	56
Water Ways Between Settling Basins and Filters	60
Wash Troughs of Filters, and Requirements	66
Wash Water Saved by Properly Designed Chemical and Filter Controllers	74
Wash Water Saved by Settling Basins	59
Wine Barrell Equivalents	153
Yard Equivalents	153
Yellow Light to Assist in Reading End Point	91

Preface

THIS volume is issued by the Engineering Bureau Water Purification, American Steel & Wire Company. It may be well to go briefly into the policies which led to its preparation, publication and circulation.

The function of the Bureau is to assist, as far as practicable, in helping either municipally or privately owned water purification plants to obtain the best and most economical results possible.

The number of these plants in the country is already large and is increasing each year. Many of these have been admirably planned and built. Others have not been so fortunate. In few branches of engineering work have such advances been made as along the lines of water purification. Some plants, built years ago, and numbered among the best at the time of construction, are now more or less obsolete, either on account of their deterioration or because of progress in the art.

Some of these older plants have been or are being remodeled, enlarged or replaced with more modern plants. Some remain as originally constructed. With all these styles and types of plants, either building or working, there has arisen many problems of design and operation.

The Engineering Bureau Water Purification of the American Steel & Wire Company was organized to exploit the use of Sulphate of Iron in these plants. It was realized from the beginning that we could only be successful in this work insofar as we made the interests of our clients our supreme care. In order to do this it was necessary to have men who could and would give our clients and possible clients such assistance as would enable them to get the best results at the lowest possible cost. It was soon found that these results could not always be secured unless certain conditions, both as to water supply and arrangement of plant, could be made effective.

At many plants these conditions were not obtainable. At some points the arrangement of the plant positively prohibited the attainment of satisfactory results even when the water supply was all that could be asked.

Where the plant arrangement was the only thing preventing the successful employment of our process and where it was apparent that the saving to be effected would warrant the expense of the necessary alterations it became necessary to make such recommendations as to permit of the process being used. It was also found that where these things could be done at the time the plant was being constructed the results were more satisfactory and economical. Such installation could be more economically made and the general efficiency of the plant improved thereby.

For these and other reasons which will be obvious it was soon found to be necessary to furnish a certain amount of engineering

advice to the city, corporation or engineer desirous of availing themselves of the services of this Bureau.

This Bureau therefore stands ready to assist in any practicable manner those cities, corporations or engineers who desire assistance in working out any of the problems connected with the design, construction or operation of Water Purification Plants.

The process known as the American Steel & Wire Company's Process employs Sulphate of Iron and caustic lime to either partially soften and purify municipal water supplies or merely purify them. During the last twelve years our engineers have encountered many difficult problems in this line of work and have obtained a large fund of information on the subject. Where this process is employed we stand ready to furnish experts to assist local operators in securing the best obtainable results and to instruct them in proper methods of operation. The services of these experts are free to those requiring or desiring them. Where trouble is found in obtaining the desired results owing to unforseen difficulties these services may be of value in overcoming the difficulty and showing how it may be avoided in the future.

Where cities are contemplating building new plants or remodelling old ones the advice of these men may be of material assistance, either in helpful criticism of plans already drawn or the working out of plans for properly carrying on the work. Where a city is in doubt as to the best course to pursue in order to attain a certain result we are ready to do all we can to assist in finding the proper solution and for such services we make no charge. Where engineers desire such assistance the same holds true.

It must be understood that where our services are asked for in either of the above cases we act only in an advisory capacity and do not prepare plans or specifications for the work to be done. We earnestly recommend on all work of this kind a thoroughly competent and reliable engineer be employed to prepare such plans and specifications.

In order to assist in this work we have prepared this volume.

The American Steel & Wire Company's Process of Water Purification

Responsibility of Public Officials

Every public official is more or less personally responsible for every death from water borne diseases which occurs within his city. The paragraphs immediately following are, therefore, of direct application to each and every public official in every city where water borne diseases and deaths are to be found.

Disease Kills Civilization

There is no doubt that disease has materially helped to overthrow civilization in the past. History abounds in tales of pestilence and from the writings of the ancients it is observed that the Egyptians of the Pharaohs were hygienic, drained the land, reared temples and cities, maintained law and order and developed the elements of literature and science. With the later decline in learning and wisdom, Egypt was visited and desolated by pestilence. Still later, Gibbon the historian denounced Egypt as the original source and breeding place of the plague.

Greece, progenitor of the most magnificent civilization of antiquity, felt the enervating influence of the lack of scientific sanitation, and under the depressing effects of disease the culture of this great people slowly but surely decayed.

The ancient Roman Empire, wonderfully promising in world wide influence, gave but little to science, and the history of her decline indicates disease as an important factor leading to her downfall. From the year 251 to 265 (fifteen years) pestilence carried off half the inhabitants of the empire. In 1343 an epidemic reduced the population of the Eternal City to 20,000. In Florence, during the scourge, upwards of a hundred thousand persons perished.

In Justinian's time the plague mortality was extraordinary, the historical record stating that within three months four to ten thousand persons died daily at Constantinople, while other cities were stripped entirely of human beings.

This epidemic traversed all Europe, and a century later it reaped a harvest in England. We are told that between the years 88 and 92 A. D. the deaths in Scotland from the plague aggregated 150,000, possibly one-half the population at that time. In 80 A. D., Rome, with a population of a million, lost her citizens at the rate of 10,000 a day. In 114 A. D., 45,000 died of plague in Wales. In 173 A. D., the Roman army was nearly decimated. Five great epidemics swept England between the years 1485 and 1665 and it was shown that the strong bodied were the most susceptible.

After the last epidemic in London, in 1665, the death rate fell to between 70 and 80 per 1,000.

During the next century it fell as low as 50. In the nineteenth century it decreased to 14 per 1,000.

Here in the United States the first year of mortality statistics (1879–80) showed a death rate of 19.8 per 1,000 and in 1912 it was 13.9, which marked a decrease of 30 per cent. The mortality from typhoid in the same time decreased 50 per cent., showing that the effectiveness of the work of sanitation and medicine has not been merely theoretical. The modern sanitarian is quite competent to rebuild the home in which the cradle of civilization was rocked.

Our present civilization, of which we are somewhat inclined to boast, is truly an improvement; but the boasting is justified only within limits. While science more nearly dominates the world than at any other time within the past, in this country of a hundred million people there are thousands who impede progress because of greed and ignorance.

Co-operation to Prevent Disease

An intelligent people must cooperate in the great work of eradication of disease, for the right to enjoy health is quite as sacred as that to possess property. As a general proposition, our sanitary laws are very good but their administration still leaves much to be desired.

To ignorance and carelessness must be attributed much of the causation of disease in the centuries gone by. Out of the throes of suffering and death of the myriads who have preceded us we have obtained a certain enlightenment, which while not perfect still makes it absurd to plead ignorance and lack of knowledge.

The day is not far distant when it will be considered a crime for a city to continue to murder its citizens by furnishing them an impure water supply. Diseases which consign thousands to the grave leave even worse results in their wake by passing on to the children a hopeless poverty, opening the gate to crime, prostitution and mendicancy. All the authorities agree that contagions react on the moral fibre of a community or people, and contrariwise, where they live under healthful conditions great advancement in government, literature and science has been made.

There is a moral obligation to be intelligent. Ignorance is a vice and when it results in injury to anyone it becomes a crime, moral, if not statutory. There is no excuse in this day for ignorance of any one in relation to the necessity for the purification of all water supplies in cities where the death rate from water borne diseases is higher than that in cities having perfectly satisfactory water.

Responsibility for and Value of Human Life

Responsibility is a word of tremendous import. Its significance is akin to trust, and those men who are responsible for and serious minded in the conduct of human affairs realize their liability to be

called to account when honored with leadership.

There are men, however, upon whom responsibility rests lightly, perhaps not wilfully but because of circumstances beyond their control and in the management of their trusts they become indifferent to the only too common signs of inefficiency, which ultimately result in retrogression, if not disaster.

The purpose of government is to protect its citizens, and a government which fails to shield the people from infection cannot be truthfully called either responsible, intelligent or moral.

The greatest asset of any city or town is the health of the citizens, and the officials who secure this in the highest degree are those who appreciate the responsibility placed upon them in this very important matter.

Preventive measures in conserving the health of the community records success in direct ratio to the number of lives saved, and it is pleasing to note that the statistics of the last century show an increase of fifteen years in the average human life. There is reason to hope that, in the future, this increase may be duplicated in a considerably shorter time, if earnest use is made of present day science.

The Value of Human Life

The value of human life is something not to be trifled with. It is measurable, in cold finance as well as in ethics. Students who have made a digest of the former viewpoint stand upon the assertion that the monetary value of a human life ranges between $1,000.00 and $7,500.00, from the ages of 70 down to 5 years, the highest value being attained at the age of 30; the lower value given is at 5 years, while the average value comes very close to $6,000.00.

In the year 1900, according to the United States Census Reports, there were 35,379 reported deaths from typhoid fever in this country. If we accept $6,000.00 as the average value of a human life, the grand monetary loss as represented in the lives lost from this one disease amounts to $212,274,000.00 in one year. It is to be noted that only a portion of the lives lost because of typhoid fever were reported and that the actual loss of life must have been considerably in excess of that reported.

It is generally assumed that the larger portion of the deaths resulting from typhoid fever are either directly or indirectly attributable to impure water. It is also generally assumed that for each case of typhoid caused by impure water there are at least ten other cases of disease other than typhoid resulting from the same cause.

Prof. Irving Fisher, of Yale University, has estimated that over 600,000 deaths occur each year in the United States which could be postponed by systematic application of scientific knowledge already available. In dollars and cents this estimate places the national loss per annum at an appalling figure.

Ignorance Breeds Disease

The plain fact is that not only does ignorance breed disease but the converse is almost as true and that disease breeds ignorance, immorality and strife. In the light of the scientific work at the present time, disease in its horrible wholesale form is controllable if it cannot be entirely eliminated. This control or elimination is possible only when there is an awakening of the sense of responsibility on the part of those who have been elevated to the high places in government. Short sighted humanity fails to appreciate nature's gifts until threatened with their loss. This is true even of the greatest of them all, life itself. It is significant of our failure to value health.

Now, Mr. Public Official, do you, as a city official, realize that you, personally, are responsible for every death from a water borne disease, which occurs in your city unless you are consistently and persistently doing everything possible to prevent such death?

Impure Water Dangerous

The most imperative need of mankind is pure water, pure air and pure food. Few water supplies in this country are pure enough to be used in their natural state. Impure water has killed more men, women and children than all the wars the world has seen. Not only may a conservative statement of this kind be made, but it may be said with equal truth that impure water is now killing, and will continue for many years to come, to kill more people than any or all probable wars. This condition is due very largely to a lack of knowledge of this truth. If every one knew and really appreciated this one fact, it would soon cease to be a fact. The reason is that if every one knew and appreciated the results of the continued use of impure water, public opinion would compel the authorities to provide a remedy.

Impure Water Unnecessary

There is scarcely any one thing more unquestionably established than the practicability of furnishing a pure, safe and satisfactory water, irrespective of the condition or degree of pollution of the available natural supplies.

An authority on this subject has emphasized this by saying: "When any one dies of typhoid fever, it is a crime, and some one should be punished; by hanging, if necessary." This may appear to be a rather harsh statement, but it is a thoroughly well established fact that typhoid is an almost wholly unnecessary and preventable disease.

Causes Disease

Many seem to believe that this well known disease is the only one caused by impure water, and this, in general with much other knowledge of the layman along sanitary lines, has little real foundation. In fact, it is estimated that impure water, while causing typhoid, really causes probably ten times as many complaints other than typhoid,

hence the danger from an impure water cannot be safely gauged by the amount of typhoid which it causes. An allowance should be made for the other and more numerous ills arising from the same source.

The main thing to be borne in mind is that impure water should not be tolerated. While good streets, lights, parks, sewers and other public utilities are important, the first and foremost essential to public health is pure water, and the only reason cities do not always have this is because the citizens do not consistently and persistently demand it. Politicians never disregard any such demand on the part of the public as a whole.

Mechanical Filtration

Various methods have been used at different times to purify public water supplies, but no real and practical solution of the problem for American cities was ever reached until American engineering genius took the matter in hand and proceeded to give the world the American or Mechanical System of Filtration.

Early Work

Some very good work was done in the early days by the Massachusetts State Board of Health. These experiments were followed on a larger scale by the famous Louisville Experimental Work in the years 1896–1897. One of the first mechanical filters for municipal use was built at Lorain, Ohio, in 1896–1897 and subjected to test in 1897. This plant was the first in practical municipal use to demonstrate the feasibility of purifying the city supply and removing 98 per cent. of the bacterial pollution under working conditions, and thus rendering the water safe and wholesome. This was proven by a long and exhaustive test lasting six months, during which time the water was subjected to at least four bacterial analyses every day except Sunday. The State Board of Health of Ohio participated in the test and accepted and recognized the results as accurate and reliable.

Since this time the art has progressed so rapidly that engineers, unless devoting their entire time and attention to the work, have been unable to keep pace with the advances made and making.

Chemical Methods

From 1897 to 1903 the method of coagulating water most generally employed required the use of alum. In the latter year, the American Steel & Wire Company's process was first employed at Quincy, Illinois. A little later it was used at Vicksburg, Mississippi, and Lorain, Ohio, at almost the same time. St. Louis followed, and since then the use of this process has extended, until nearly one hundred cities now employ it to purify their water supplies.

Principles

All chemical methods for water purification by mechanical filtra-

tion are based upon a relatively simple principle. Every housewife knows that if she mixes the white of an egg with her coffee and heats it, the egg albumen will coagulate and in so doing will gather the grounds together and leave the coffee clear and brilliant. One thing not so generally known is that when this is done all of the egg is removed in the process, none of it remaining in the clear resultant coffee. It is on this simple principle that all chemical methods of water purification by mechanical filtration are based.

While this principle is employed, none of the methods used in mechanical filtration requires the water to be heated, although all of them would be expedited if it were practical to do so.

The reason for our ability to secure results without heat is found in the fact that water contains enough chemical compounds in solution in the natural state to unite with the chemicals which we employ, and when the chemical compounds present in the water do so unite with those added, a new chemical compound is formed and this new compound is insoluble in water just as the white of egg becomes insoluble by heating the coffee, and all of the chemicals added in the water are removed in the process just as the egg is removed from the coffee. Likewise, as the egg clears the grounds from the coffee by coagulation, so also does the chemical coagulation clear the water from mud and bacteria and by so doing the water is purifi and clarified and rendered suitab for further treatment by mecha ical filtration.

Action of Chemicals

The action of coagulants is brie described in City Document No. 1 Providence, R. I., as follows:

> "If the diameter of matter floating in water is much less than that of the interstices between the grains of sand composing the filter bed, such matter, except so much as is caught upon the sharp edges of the quartz, will go right through the filter with the water. Now, if a substance could be introduced, drop by drop, in the water before it comes to the filter, which would have the effect of curdling this matter together, so that every hundred or so of the smaller particles were made to join together and become one large particle, much as vapor or steam is condensed in drops, it would follow that they would be caught and held from going through the filter."

The American Steel & Wire Company's Process—How It Works

In the American Steel & Wi Company's process, this is accom plished by adding very small qua tities of sulphate of iron and caust lime to the water as it passes fro the pumps to the filters. The a tion is the same as when coffee cleared by means of the white of egg. No white of egg goes to t drinker of the coffee. It is turned out with the grounds, a likewise no sulphate of iron caustic lime goes to the drinker the water. They unite with the i purities in the water and settle o

in feathery flocks in the settling basin or on top of the filter, and are washed out together with the impurities when the filter is washed.

No Chemicals Left

Analysis of the filtered water shows no trace of either sulphate of iron or caustic lime. The feathery floculent hydroxide of iron or magnesia; monocarbonate of lime or magnesia produced in the process forms an excellent material of insoluble mineral matter which catches and retains all small particles in the water.

Bacteria, like fine clay particles so small as to pass through the sand filter bed, are caught and retained by the filtering layer of mineral matter and the pure water passes through bright, clear and sparkling.

Stages

In a modern mechanical filter plant, there are several well-defined stages of the process of purification. These may be noted in the order of their occurrence as follows:

First, bringing the raw water into the plant.

Second, chemical treatment of the raw water.

Third, formation of the coagulation.

Fourth, sedimentation of the suspended matter.

Fifth, filtration.

Sixth, high service distribution.

Water Supplied

In general, there are two different methods in use to bring the natural water into the plant. Where the conditions are such as to permit, it is customary to locate the plant at a lower level or lesser elevation than the minimum level obtaining in the raw water supply, and to conduct the water into and through the purification system by gravity.

Lift

In few cases, however, are the conditions such as to allow of this. Usually the plant must be placed above the level of the natural supply, and hence it becomes necessary to pump the water from the lower level up to that required to allow it to pass through the purification works by gravity.

The distance through which the water is lifted in order to do this varies largely in different plants. In some it is only a few feet, in others it may be from forty to seventy feet, while in others it may be even greater than this.

Pumps

Where the lift is low, it is the usual practice to employ a single stage centrifugal pump. This may be driven by belt from a steam engine or motor, or, in a few places, from gas engines. In some instances the pump is coupled direct to a steam engine of either the turbine or reciprocating type, to gas engine or to motor, while in isolated cases, the high service pumps may be used to drive a water wheel directly connected to the centrifugal pumps. In such instances, the discharge from the water motor

returns to the clear water reservoir. In some cases, water wheels or water turbines driven by water power are used to drive the pumps to lift the water into the plant. In others the low service pumps or even high service pumps may be employed to lift the water to a reservoir from which it flows by gravity to the purification plant, or the water may pass by gravity into a reservoir from which it passes, also by gravity, into the plant.

Point of Treatment

There are a few plants where the water is treated with chemicals as it enters these reservoirs and is then lifted to the filter, but no engineer with even a fair knowledge of the art would think of advising this with our present knowledge.

The method of introducing the water into the plant is of no moment in the process of purification, save in the last named instance. The main object is to make the lift to the plant as economically and certainly as possible.

Chemical Treatment

With the water flowing into the plant, the next step is its proper treatment with chemicals. The difficulties here are many and varied, and seldom the same in any two plants. Too much stress cannot be placed upon the importance attaching to this matter. Most of the plants which fail either partially or wholly, fail because of faults in applying or handling the chemicals.

Preparation of Chemicals

Before the iron sulphate can be applied it is necessary to prepare a solution of known definite strength or to arrange to add a known and predetermined weight of the material to a known volume of water. The same statement holds true as to the lime.

Engineering Difficulties

Several different ways of doing this obtain. All are possessed of advantages and disadvantages and much engineering ability has been and is being directed towards the problems involved. Much of the difficulty in overcoming the troubles arises from the lack of comprehension on the part of engineers of the real troubles and demands. This occurs because designing engineers as a rule are not operating engineers and are thus unable to obtain a correct knowledge of the facts, for the reason that what knowledge they obtain is second hand and some of it unreliable.

The operator may have a strong disinclination to inform the designing engineer that trouble exists, for fear of being considered incompetent or through fear of angering the designer by criticism. Furthermore, the operator may be really incompetent to formulate a proper criticism. If every designing engineer had to operate every plant he designs for six months, he might design fewer plants, but it is hardly conceivable that he would not design better ones. For this reason the opinions of *competent* operating

men should receive much more careful consideration than they have in the past.

In order to commence at the proper point, we shall begin with a description and the handling of the chemicals from the railroad station adjacent the plant.

Sulphate of Iron

Sulphate of iron is a pale green salt. In the old process of manufacture the size and quality varied within rather large limits. It usually varied quite as much in the water content, both of crystallization and mechanical moisture.

The chemical formula of this substance is $FeSO_4$, $7H_2O$. This means that one part of iron with an atomic weight of 56.0, one part of sulphur with an atomic weight of 32.0, and four parts of oxygen, each with an atomic weight of 16.0, or a combined one of 64.0, are united with seven parts of water each having a molecular weight of 18.0 or a combined one of 126.0, to form one part of sulphate of iron with a molecular weight of 278.0, of which 45.32 per cent. is water of crystallization.

Strength

When of exactly this composition and free from all impurities, the material is 100 per cent. pure or, as the chemist puts it, chemically pure. The water of crystallization amounts to 45.32 per cent. and if part of the water be driven off, it will be evident that each pound of the material will contain less water and more iron sulphate, and that the strength of the material, as far as the percentage of iron content is concerned, will be increased, thus the strength may go to 102 per cent., 104 per cent., or even 106 per cent. by driving off part of the water of crystallization.

In the process of manufacture this is actually done, and the new product, called sugar sulphate of iron, usually averages about 102 per cent. strength.

Larger Crystals

The older material in larger crystals contained all the water of crystallization and in addition some moisture mechanically held, and seldom ran above 94 to 96 per cent. strength, the balance being water.

There were two grades, known as prime green, selects or stick crystals, and seconds or bottoms. The prime green or stick crystals were large crystals from half inch to four inches in size, and formed the best quality. Bottoms or seconds were small, large and medium size crystals, containing more dirt, water and impurities, and were of second quality.

Sugar Sulphate

These two grades have been largely restricted in manufacture and replaced by the sugar sulphate of iron. This is finely granular and derives its name from its appearance, which is very much like granulated sugar except for its pale green

color. It does not deteriorate with age if kept in a dry, cool place. If kept in a very warm room for several months, it may set into a mass more or less difficult to break up, but this does not affect its strength injuriously or render it less suited for any commercial purpose except to slightly increase the time required to dissolve it.

Packages

Sulphate of iron is shipped in five different forms of packages: in 25-lb. paper cartons; 100-lb. bags; 200-lb. bags; 350 to 400-lb. barrels, and in bulk. Where it can be properly handled it is cheaper in bulk than in 200-lb. bags. The 100-lb. bag or barrel is the next cheapest, and the 25-lb. carton costs a little more than an equivalent quantity in barrels or 100-lb. bags.

Purchasing

Most of the material for water purification is sold either in bulk, 200-lb. bags, 100-lb. bags or in barrels. That packed in cartons should never be purchased for this use. It is usually better to buy in bulk if proper provisions are made to handle it. If this cannot be done, the 100-lb. bag or barrels is the next best proposition. The 200-lb. bag is cheaper than the barreled product or the 100-lb. bag, but harder to handle and usually less satisfactory. Ordinarily it is not feasible to buy in bulk if the material is to be hauled to the plant by wagon.

Handling

If the car can be switched up t the chemical room on railroad sidi and if proper unloading and stora facilities are available, then pu chase in bulk becomes advisab and profitable. Some form of m chanical unloader and conveyor storage is desirable. Men cann unload cars with a shovel, unle provided with aspirators, as tl dust from the material, while n so objectionable as some oth chemicals used for water purific tion work, is not pleasant to breatl and does a workman no real goo

If purchased in 100-lb. bags, can be unloaded from a car hauled by wagon with great fac ity, and it is easily and economical handled and stored. The bags a of good quality cotton duck a free from lint, hence they do n shed fibres, such as always con from jute bags, to stop up orific and pipes and cause trouble arou the plant in many ways. Usually ready sale of empty bags at a go price may be found. This size pac age can be stored very conve iently in almost any dry stora place, to excellent advantage, a are so accurately weighed a packed and contain so nearly t exact amount of 100 pounds, th unless the bag is torn, it is nev necessary to weigh it.

This is a considerable conve ience, saving time and labor. F plants desiring to buy bulk sulpha of iron, the provisions to hand it satisfactorily vary with loc conditions, and information c

be secured from the manufacturer regarding this by asking for it. It is not a subject which can be gone into in a book of this size.

When the material has been unloaded and stored in the chemical stock room of the plant, it is ready for use.

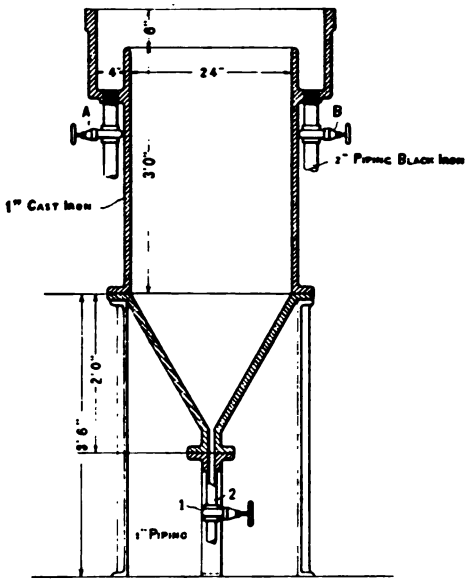
Solubility

Every one knows that sugar is very soluble in water, and yet a teaspoonful of sugar can be placed in a cup of water, tea, or coffee, and unless stirred, it dissolves very slowly. So also sulphate of iron, while very soluble, if placed in water and undisturbed, will not go into solution very rapidly; therefore, some arrangement should be provided to expedite bringing it into solution. It is only slowly affected by running water passing over it, and has a tendency to fall through a screen; but if a flow of water can be forced up through it, a very strong solution can be easily and quickly prepared. We show a sketch of a device which has proven very effective and satisfactory for this purpose.

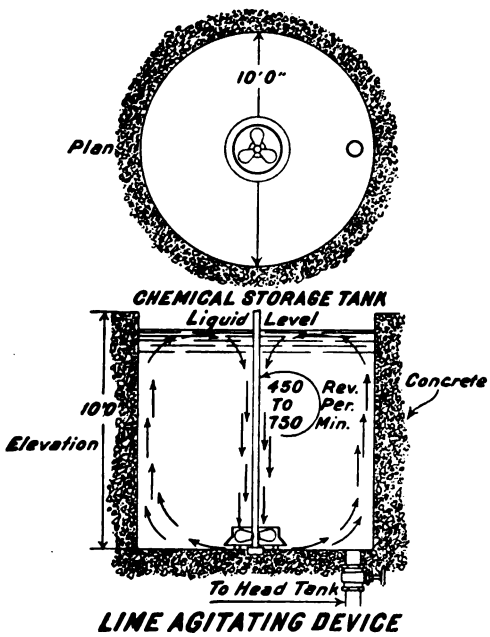
Sulphate of iron is placed in the cylinder having a conical shaped bottom and the valve 1 is opened on the water main 2. The pressure forces the water upward through the iron sulphate and valve A or B is opened to carry the dissolved iron sulphate to the solution tank to be charged. The sulphate is quickly dissolved and carried away to the storage or chemical solution tank, which, when filled with water to the proper mark, gives us our chemical solution.

Stirring Solution

It is not enough to run this into the chemical solution tank and then fill the tank to the mark and proceed to use the solution without further ado, as is done in some places; it is essential that the strength of the solution should be homogeneous throughout the tank, and this can be obtained only by thoroughly agitating the contents of the tank after it has been filled. If this is not done, the bottom layers of the solution will be stronger and heavier than the top layers, and if used without stirring, that first drawn from the tank may be very much stronger than that drawn from the nearly empty tank. Drawing off always occurs from the bottom and thus the stronger solution is first used, the top being the last to be drawn off. In fact, practically all of the iron sulphate may be drawn off before the tank has been half emptied, and the last half tank may, under these conditions, be of absolutely no value as a chemical solution to treat water. The contents of the tank should therefore be thoroughly agitated after the tank has been filled. With some chemicals, it does not matter materially how the solutions are stirred or agitated. Any method which will result in making and maintaining solutions of homogeneous strength is all that is required in such cases.



Dissolving Tank For Sulphate Of Iron.



LIME AGITATING DEVICE

Air for Stirring

With sulphate of iron, however, this does not hold true. Air agitation should never be used for this work. The air passing through the solution tends to oxidize the iron solution, and thus cause it to lose strength as well as to bring about other undesirable results. A mechanical method or even the use of a plasterer's hoe, is preferable to the use of air agitation.

Mechanical Stirring

In most of the modern plants, some form of stirring device, power driven, is employed. Some forms of these devices are less desirable than others, although most of them are sufficient to accomplish the desired results, viz: that of making and maintaining a homogeneous strength of solution from the time the tank is filled until it is empty, and keeping the tank free from mud composed largely of iron oxide or hydrate. The power required to drive the stirring device is small in the case of this solution. Practically all that is required is to cause a small circulation from the bottom of the tank to the top and from the top to the bottom. An impeller may be placed in the bottom of the tank and driven by any type of motor. If the blades of the impeller sweep the larger part of the area of the tank bottom, the speed of drive may be quite slow. In some cases it does not exceed four revolutions per minute. If the blades of the impeller are shorter than this, the number of revolutions per minute should be increased proportionally.

Pumping

In some plants, instead of using impellers or stirring devices of this type, a small pump is used to create a circulation in the tank. This pump may be a bronze lined centrifugal or reciprocating type, as preferred. In either case, it is necessary to use a bronze lined pump, as other materials are too quickly affected by the solution.

Acid Resisting Metals

A solution of sulphate of iron, like alum, acts similarly to a weak acid solution, and while not so destructive as alum solutions, it is good practice to use acid resisting metals for all pipe lines, pumps, orifices, impeller blades, and other metal parts which are used to handle it. Chemical tanks may be made of wood or concrete, while the dissolving funnel, page 18, may be of either concrete, heavy sheet steel, or cast iron, as preferred. The pumps may be placed above, below, or on a level with the top of the tank.

The suction should extend to the bottom of the tank and the discharge may occur above the maximum level in the tank or at any point below. We prefer to see both suction and discharge reach the bottom of the tank, the discharge being made to occur in a horizontal plane and on a tangent to the curve of the tank, with the end of the discharge resting on the tank bottom. If a head tank is placed at a higher

General View

Equipment by
Norwood Engineering Co.

Fargo Filter Plant

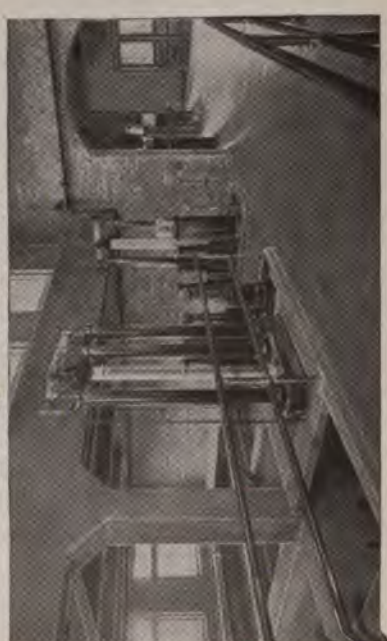
Filter Operating Floor

Machinery Room

Pipe Gallery

Views in Fargo Filter Plant

Mixing Chamber



Earl Type Filter Controllers

level than the top of the tank, and a pump is required to lift the chemical solution to the head tank, as is done at some stations, the pump should be of ample capacity and lift considerably more solution to the tank than will be required for use.

Head Tank

The head tank should be provided with an overflow in this case, and this overflow going back to the solution tank through a discharge line similar to that previously described, forms a very satisfactory form of agitation apparatus. One of the most satisfactory forms of these devices will be described under the section relating to the handling of lime.

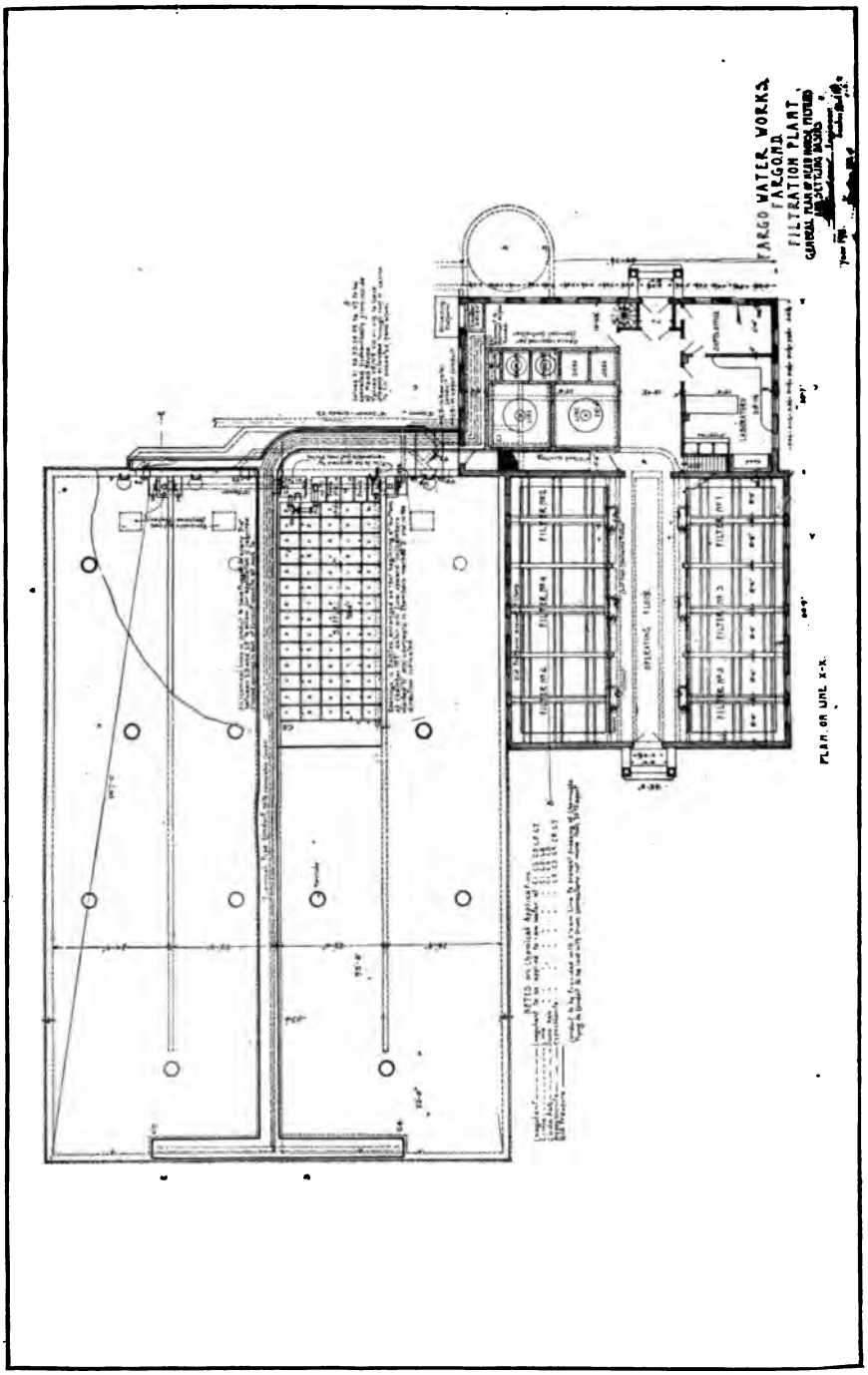
Quantity Used

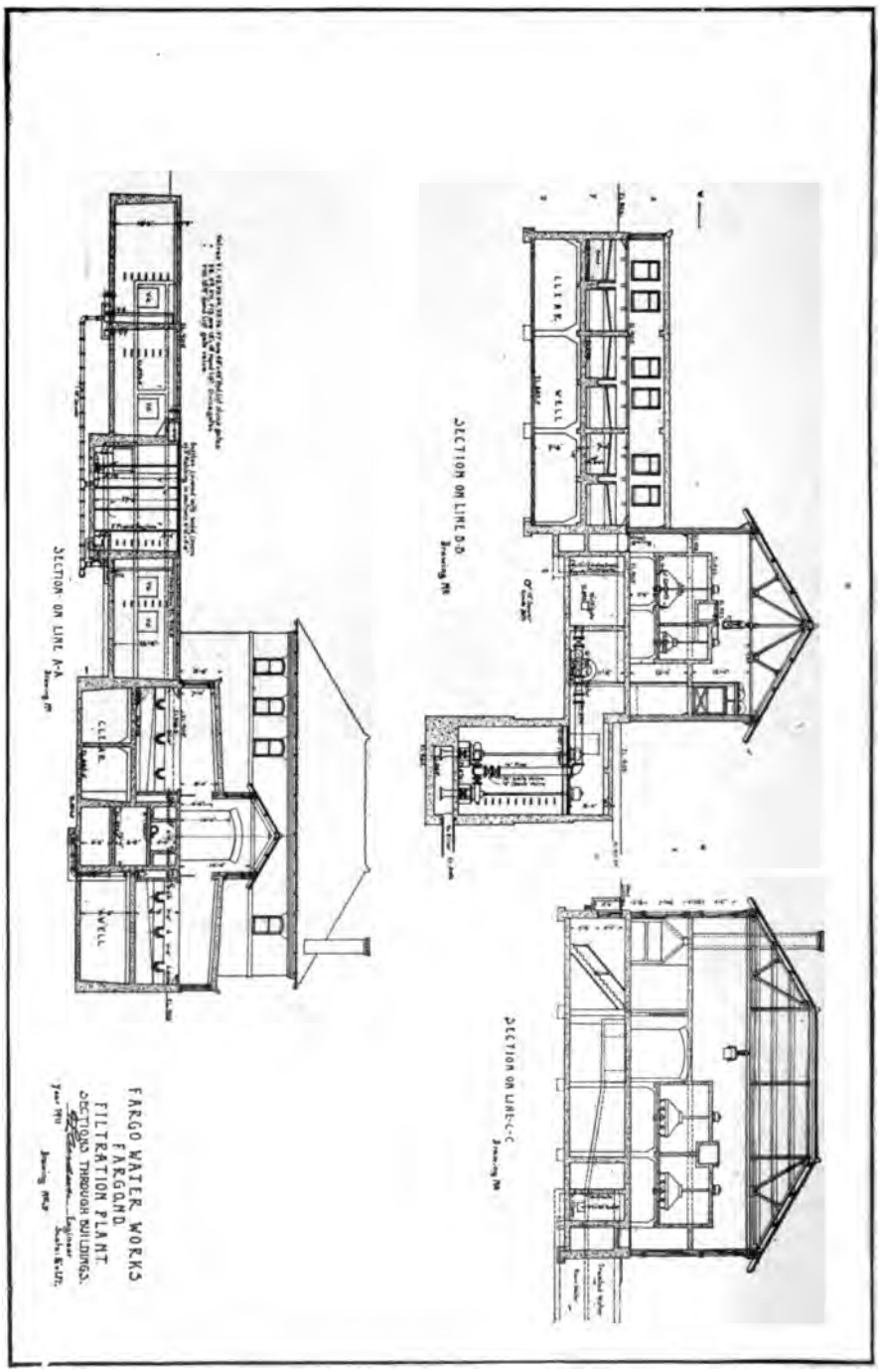
With the solution thus made up and ready to apply, the next point to receive attention is that of ascertaining how much to apply and how to do so. Each plant has its own limitations in this respect and some of them are remarkable chiefly for the strictness of these limitations. The ideal to be sought is, first, to ascertain just how much should be applied to obtain the best results, and to do so with the greatest economy, and then to apply the exact amount required. It is much easier to state this than to accomplish it, even in the best plants yet built, and in most of the others it is practically impossible to even approach the ideal in either way.

If it were possible in these plants to apply the exact amount required, or sought, it would then become a relatively easy matter to determine after a certain number of trials just how much should be used to reach the acme of perfect results and greatest economy, but inasmuch as this is usually impractical, we are therefore always left in doubt as to the exact amount required to obtain the best results, and can only reach a conclusion approximately correct in this respect. These difficulties are common to all chemical purification methods.

Difficulties

The reasons for our inability to do better are twofold. Unless we are able to actually apply a known quantity to a supply and see what it accomplishes, we can hardly predicate what can be accomplished by using another quantity. If we cannot tell just how much should be used, we can only approximate the desired result, even if we knew and were able to apply exactly the desired or predetermined quantity. While, by adding a known and definite quantity, by weight, of chemical, to a known definite quantity of water by volume, we can prepare a chemical solution containing just so many grains or pounds of chemical per gallon of solution, and while we can arrange devices to automatically apply this solution at a rate which is sufficiently constant to be considered a fixed rate, and thus in a given period of time we can be certain that we have added just so many grains or pounds of chemicals to the water during each minute of


FARGO WATER WORKS
FARGO
FILTRATION PLANT
PLAN OR UNIT X-X.


SECTION ON LINE B-B
SECTION ON LINE A-A
SECTION ON LINE C-C
FARGO WATER WORKS
FARGO, N.D.
FILTRATION PLANT
SECTIONS THROUGH BUILDINGS

this time period, this does not permit us to know how many grains of chemicals we have added to each gallon of water passing into the plant, unless we know that the quantity or volume of water has not varied at any period of this time interval, and unless we are able to know just how many gallons have passed during each minute of the period in question.

In but very few plants is it possible to obtain conditions which warrant us in assuming that the same quantity of water enters the plant from minute to minute during any considerable period of time, and even if this can be known, the number of plants where we can know even approximately how much is thus constantly flowing are still fewer.

Hence, we have to do the best we can to ascertain *about* how much water is entering during the times of maximum and minimum use and try to adjust our flow of chemicals to meet these flows as accurately as conditions will permit.

Head Tank

One can usually ascertain with a fair degree of certainty about what volume of water is pumped during twenty-four hours and can also determine about how many grains per gallon of chemicals it is desirable to apply. In most instances, some form of head tank is employed to apply the chemical solution, and some size or even many differing sizes of orifices may be utilized in this head box to vary the rate of flow through the box. In most of these the head or level of solution over the orifice is fixed and remains constant. In a few, the head varies. Even in the latter case it is the usual practice to provide a number of different sized orifices and thus in an equipment of this kind we have two ways of changing the rate of chemical feed. First, by varying the head over the orifice, or, second, by varying the size of the orifice. If the head over the orifice is fixed, it is usual to fix it at one foot, and if this is the case, it is relatively simple to calibrate the different sized orifices and ascertain just how many gallons of chemical solution per minute each orifice will discharge, and also to obtain a coefficient of discharge for each orifice.

Chemical Orifices

The method generally employed to do this is to first accurately determine the size of the orifice to be used and the area in square inches. A standard orifice is one which is made in a plane surface, with sharp inner edges, as shown in the sketch below.

B is a plane surface through which the orifice, A, is made. The water rests on B and flows past the thin knife edges of the orifice, falling free into air. The plane surface around the periphery of A must extend in a plane in all directions for at least twice the diameter of the orifice, A.

Under a one-foot head the velocity of flow of water through the

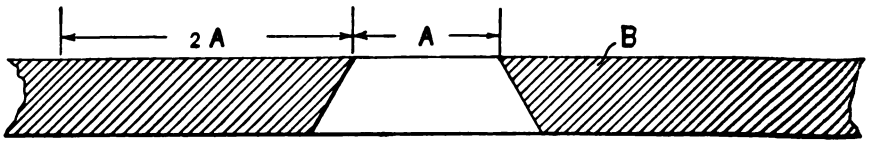
orifice will be 8.02 feet per second. Such an orifice, while passing a velocity of 8.02 feet per second, will not discharge a stream of the full size of the orifice at this speed. If it did, the factor for discharge would be unity; whereas, the actual coefficient of discharge for such an orifice is usually estimated at .62. In an orifice which differs from this the coefficient of discharge will or may vary quite a degree from .62, and hence the coefficient must be obtained by calibration.

The following table, devised by Mr. Joseph Rowell, Erecting Filtration Engineer, Pittsburgh, Pa., gives the discharges for standard circular orifices under a one-foot head, with coefficients of unity 1.00, and .62 for different sized orifices. The discharges are in gallons per minute and also gallons per day of twenty-four hours.

Diameters of orifices advance from zero to two inches by hundredths and fractions of inches. Discharge in gallons is given for one minute and for day of twenty-four hours. One column is calculated for a coefficient of 0.62 and one column for unity. To calculate actual discharge in gallons per minute or per diem for any other coefficient than 0.62, multiply the tabular values in the unity column by the desired coefficient.

This table was computed by the formulae: $\frac{(8.02 \times 12 \times 60)}{231} \times A =$ unity discharge in gallons per minute. $\frac{(8.02 \times 12 \times 60 \times .62)}{231} \times A =$ discharge in gallons per minute for coefficient 0.62. Where (A) = area of orifice in square inches, first formula gives Factor A a value of 25, second formula gives Factor A a value of 15.5.

The area in square inches multiplied by factor gives tabular value for discharge in gallons per minute. Some errors of 1 in the last significant figure.



STANDARD ORIFICE

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot

DIMENSIONS IN INCHES			COEFFICIENT = 1.00		COEFFICIENT = 0.62	
Diameters		Area	Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
	.00	.000000	.000000	0.000	.0000000	0.00000
	.01	.000079	.001975	2.844	.0012245	1.76328
1–64	.0156	.00019	.00475	6.84	.0029450	4.2408
	.02	.00031	.00775	11.16	.004805	6.1912
	.03	.00071	.01775	25.56	.011005	15.8472
1–32	.0312	.00077	.01925	27.72	.011935	17.1864
	.04	.00126	.03150	45.36	.019530	28.1232
3–64	.0468	.00173	.04325	62.28	.026815	38.6136
	.05	.00196	.04900	70.56	.030380	43.7472
	.06	.00283	.07075	101.88	.043865	63.1656
1–16	.0625	.00307	.07675	110.52	.047585	68.5224
	.07	.00385	.09625	138.60	.059675	85.9320
5–64	.0781	.0048	.1200	172.80	.07440	107.1360
	.08	.0050	.1250	180.00	.07750	111.6000
	.09	.0063	.1575	226.80	.09765	140.6160
3–32	.0937	.0069	.1725	248.40	.10695	154.0080
	.10	.0078	.1950	280.80	.12090	174.0960
7–64	.1093	.0094	.2350	338.40	.14570	209.8080
	.11	.0095	.2375	342.00	.14725	212.0400
	.12	.0113	.2825	406.80	.17515	252.2160
1–8	.1250	.0123	.3075	442.80	.19065	274.5360
	.13	.0133	.3325	478.80	.20615	296.8560
	.14	.0154	.3850	554.40	.23870	343.7280
9–64	.1406	.0155	.3875	558.00	.24025	345.9600
	.15	.0177	.4425	637.20	.27435	395.0640
5–32	.1562	.0192	.4800	691.20	.29760	428.5440
	.16	.0201	.5025	723.60	.31155	448.6320
	.17	.0227	.5675	817.20	.35185	506.6640
11–64	.1718	.0232	.5800	835.20	.35960	517.8240
	.18	.0254	.6350	914.40	.39370	566.9280
3–16	.1875	.0276	.6900	933.60	.42780	616.0320
	.19	.0284	.7100	1022.40	.44020	633.8880
	.20	.0314	.7850	1130.40	.48670	700.8480
13–64	.2031	.0324	.8100	1166.40	.50220	723.1680
	.21	.0346	.8650	1245.60	.53630	772.2720
7–32	.2187	.0376	.9400	1353.60	.58280	839.2320
	.22	.0380	.9500	1368.00	.58900	848.1600
	.23	.0415	1.0375	1494.00	.64325	926.2800
15–64	.2343	.0431	1.0775	1551.60	.66805	961.9920
	.24	.0452	1.1300	1627.20	.70060	1008.8640
1–4	.2500	.0491	1.2275	1767.60	.76105	1095.9120
	.26	.0531	1.3275	1911.60	.82305	1185.1920
17–64	.2656	.0554	1.3850	1994.40	.85870	1236.5280
	.27	.0573	1.4325	2062.80	.88815	1278.9360
	.28	.0616	1.5400	2217.60	.95480	1374.9120
9–32	.2812	.0621	1.5525	2235.60	.96255	1386.0720
	.29	.0661	1.6525	2379.60	1.02455	1475.3520
19–64	.2968	.0692	1.7300	2491.20	1.07260	1544.5440

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot—Continued

DIMENSIONS IN INCHES		Area	COEFFICIENT = 1.00		COEFFICIENT = 0.62	
Diameters			Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
	.30	.0707	1.7675	2545.20	1.09585	1578.0240
	.31	.0755	1.8875	2718.00	1.17025	1685.1600
5–16	.3125	.0767	1.9175	2761.20	1.18885	1711.9440
	.32	.0804	2.0100	2894.40	1.24620	1794.5280
21–64	.3281	.0846	2.1150	3045.60	1.31130	1888.2720
	.33	.0855	2.1375	3078.00	1.32525	1908.3600
	.34	.0908	2.2700	3268.80	1.40740	2026.6560
11–82	.3437	.0928	2.3200	3340.80	1.43840	2071.2960
	.35	.0962	2.4050	3463.20	1.49110	2147.1840
23–64	.3593	.1014	2.5350	3650.40	1.57170	2263.2480
	.36	.1018	2.5450	3664.80	1.57790	2272.1760
	.37	.1075	2.6875	3870.00	1.66625	2399.4000
3–8	.3750	.1104	2.7600	3974.40	1.71120	2464.1280
	.38	.1134	2.8350	4082.40	1.75770	2531.0880
	.39	.1195	2.9875	4302.00	1.85225	2667.2400
25–64	.3906	.1198	2.9950	4312.80	1.85690	2673.9360
	.40	.1257	3.1425	4525.20	1.94835	2805.6240
13–32	.4062	.1296	3.2400	4665.60	2.00880	2892.6720
	.41	.1320	3.3000	4752.00	2.04600	2946.2400
	.42	.1385	3.4625	4986.00	2.14675	3091.3200
27–64	.4218	.1398	3.4950	5032.80	2.16690	3120.3360
	.43	.1452	3.6300	5227.20	2.25060	3240.8640
7–16	.4375	.1503	3.7575	5410.80	2.32965	3354.6960
	.44	.1521	3.8025	5475.60	2.35755	3394.8720
	.45	.1590	3.9750	5724.00	2.46450	3548.8800
29–64	.4531	.1613	4.0325	5806.80	2.50015	3600.2160
	.46	.1662	4.1550	5983.20	2.57610	3709.5840
15–32	.4687	.1726	4.3150	6213.60	2.67530	3852.4320
	.47	.1735	4.3375	6246.00	2.68925	3872.5200
	.48	.1810	4.5250	6516.00	2.80550	4039.9200
31–64	.4843	.1843	4.6075	6634.80	2.85665	4113.5760
	.49	.1886	4.7150	6789.60	2.92330	4209.5520
½	.5000	.1963	4.9075	7066.80	3.04265	4381.4160
	.51	.2043	5.1075	7354.80	3.16665	4559.9760
33–64	.5156	.2088	5.2200	7516.80	3.23640	4660.4160
	.52	.2124	5.3100	7646.40	3.29220	4740.7680
	.53	.2206	5.5150	7941.60	3.41930	4923.7920
17–32	.5312	.2217	5.5425	7981.20	3.43635	4948.3440
	.54	.2290	5.7250	8244.00	3.54950	5111.2800
35–64	.5468	.2349	5.8725	8456.40	3.64095	5242.9680
	.55	.2376	5.9400	8553.60	3.68280	5303.2320
	.56	.2463	6.1575	8866.60	3.81765	5497.4160
9–16	.5625	.2485	6.2125	8946.00	3.85175	5546.5200
	.57	.2552	6.3800	9187.20	3.95560	5696.0640
37–64	.5781	.2625	6.5625	9450.00	4.06875	5859.0000
	.58	.2642	6.6050	9511.20	4.09510	5896.9440
	.59	.2734	6.8350	9842.40	4.23770	6102.2880
19–32	.5937	.2769	6.9225	9968.40	4.29195	6180.4080

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot—Continued

DIMENSIONS IN INCHES			COEFFICIENT=1.00		COEFFICIENT=0.62	
Diameters		Area	Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
	.60	.2827	7.0675	10177.20	4.38185	6309.8640
39–64	.6093	.2916	7.2900	10497.60	4.51980	6508.5120
	.61	.2922	7.3050	10519.20	4.52910	6521.9040
	.62	.3019	7.5475	10868.40	4.67945	6738.4080
5–8	.6250	.3068	7.6700	11044.80	4.75540	6847.7760
	.63	.3117	7.7925	11221.20	4.83135	6957.1440
	.64	.3217	8.0425	11581.20	4.98635	7180.3440
41–64	.6406	.3223	8.0575	11602.80	4.99565	7193.7360
	.65	.3318	8.2950	11944.80	5.14290	7405.7760
21–32	.6562	.3382	8.4550	12175.20	5.24210	7548.6240
	.66	.3421	8.5525	12315.60	5.30255	7635.6720
	.67	.3526	8.8150	12693.60	5.46530	7870.0320
43–64	.6718	.3545	8.8625	12762.00	5.49475	7912.4400
	.68	.3632	9.0800	13075.20	5.62960	8106.6240
11–16	.6875	.3712	9.2800	13363.20	5.75360	8285.1840
	.69	.3739	9.3475	13460.40	5.79545	8345.4480
	.70	.3848	9.6200	13852.80	5.96440	8588.7360
45–64	.7031	.3883	9.7075	13978.80	6.01865	8666.8560
	.71	.3959	9.8975	14252.40	6.13645	8836.4880
23–32	.7187	.4057	10.1425	14605.20	6.28835	9055.2240
	.72	.4072	10.1800	14659.20	6.31160	9088.7040
	.73	.4185	10.4625	15066.00	6.48675	9340.9200
47–64	.7343	.4236	10.5900	15249.60	6.56580	9454.7520
	.74	.4301	10.7525	15483.60	6.66655	9599.8320
3–4	.7500	.4418	11.0450	15904.80	6.84790	9860.9760
	.76	.4536	11.3400	16329.60	7.03080	10124.3520
49–64	.7656	.4596	11.4900	16545.60	7.12380	10258.2720
	.77	.4657	11.6425	16765.20	7.21835	10394.4240
	.78	.4778	11.9450	17200.80	7.40590	10664.4960
25–32	.7812	.4793	11.9825	17254.80	7.42915	10697.9760
	.79	.4902	12.2550	17647.20	7.59810	10941.2640
51–64	.7968	.4988	12.4700	17956.80	7.73140	11133.2160
	.80	.5027	12.5675	18097.20	7.79185	11220.2640
	.81	.5153	12.8825	18550.80	7.98715	11501.4960
13–16	.8125	.5185	12.9625	18666.00	8.03675	11572.9200
	.82	.5281	13.2025	19011.60	8.18555	11787.1920
53–64	.8281	.5384	13.4600	19382.40	8.34520	12017.0880
	.83	.5411	13.5275	19479.60	8.38705	12077.3520
	.84	.5542	13.8550	19951.20	8.59010	12369.7440
27–32	.8437	.5591	13.9775	20127.60	8.66605	12479.1120
	.85	.5675	14.1875	20430.00	8.79625	12666.6000
55–64	.8593	.5795	14.4875	20862.00	8.98225	12934.4400
	.86	.5809	14.5225	20912.40	9.00395	12965.6880
	.87	.5945	14.8625	21402.00	9.21475	13269.2400
7–8	.8750	.6013	15.0325	21646.80	9.32015	13421.0160
	.88	.6082	15.2050	21895.20	9.42710	13575.0240
	.89	.6221	15.5525	22395.60	9.64255	13885.2720
57–64	.8906	.6229	15.5725	22424.40	9.65495	13903.1280

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot—Continued

DIMENSIONS IN INCHES			COEFFICIENT=1.00		COEFFICIENT=0.62	
Diameters		Area	Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
	.90	.6362	15.9050	22903.20	9.86110	14199.9840
29-32	.9062	.6450	16.1250	23220.00	9.99750	14396.4000
	.91	.6504	16.2600	23414.40	10.08120	14516.9280
	.92	.6648	16.6200	23932.80	10.30440	14838.3360
59-64	.9218	.6676	16.6900	24033.60	10.34780	14900.8320
	.93	.6793	16.9825	24454.80	10.52915	15161.9760
15-16	.9375	.6903	17.2575	24850.80	10.69965	15407.4960
	.94	.6940	17.3500	24984.00	10.75700	15490.0800
	.95	.7088	17.7200	25516.80	10.98640	15820.4160
61-64	.9531	.7133	17.8325	25678.80	11.05615	15920.8560
	.96	.7238	18.0950	26056.80	11.21890	16155.2160
31-32	.9687	.7271	18.4275	26535.60	11.42505	16452.0720
	.97	.7390	18.4750	26604.00	11.45450	16494.4800
	.98	.7543	18.8575	27154.80	11.69165	16835.9760
63-64	.9843	.7605	19.0125	27378.00	11.78775	16974.3600
	.99	.7698	19.2450	27712.80	11.93190	17181.9360
1	1.000	.7854	19.6350	28274.40	12.17370	17530.1280
	1.01	.8012	20.0300	28843.20	12.41860	17882.7840
1-64	1.0156	.8101	20.2525	29163.60	12.55650	18081.4320
	1.02	.8171	20.4275	29415.60	12.66500	18237.6720
	1.03	.8332	20.8300	29995.20	12.91460	18597.0240
1-32	1.0312	.8352	20.8800	30067.20	12.94560	18641.6640
	1.04	.8495	21.2375	30582.00	13.16720	18960.8400
3-64	1.0468	.8606	21.5150	30981.60	13.33930	19208.5920
	1.05	.8659	21.6475	31172.40	13.42140	19326.8880
	1.06	.8825	22.0625	31770.00	13.67870	19697.4000
1-16	1.0625	.8866	22.1650	31917.60	13.74230	19788.9120
	1.07	.8992	22.4800	32371.20	13.93760	20070.1440
5-64	1.0781	.9128	22.8200	32860.80	14.14840	20373.6960
	1.08	.9161	22.9025	32979.60	14.19955	20447.3520
	1.09	.9331	23.3275	33591.60	14.46405	20826.7920
3-32	1.0937	.9394	23.4850	33818.40	14.56070	20967.4080
	1.10	.9503	23.7575	34210.80	14.72965	21210.6960
7-64	1.1093	.9664	24.1600	34790.40	14.97920	21570.0480
	1.11	.9677	24.1925	34837.20	14.99935	21599.0640
	1.12	.9852	24.6300	35467.20	15.27060	21989.6640
1-8	1.1250	.9940	24.8500	35784.00	15.40700	22186.0800
	1.13	1.0029	25.0725	36104.40	15.54495	22384.7280
	1.14	1.0207	25.5175	36745.20	15.82085	22782.0240
9-64	1.1406	1.0217	25.5425	36781.20	15.83635	22804.3440
	1.15	1.0387	25.9675	37393.20	16.09985	23183.7840
5-32	1.1562	1.0499	26.2475	37796.40	16.27345	23433.7680
	1.16	1.0568	26.4200	38044.80	16.38040	23587.7760
	1.17	1.0751	26.8775	38703.60	16.66405	23996.2320
	1.1718	1.0784	26.9600	38822.40	16.71520	24069.8880
	1.18	1.0936	27.3400	39369.60	16.95080	24409.1520
3-16	1.1875	1.1075	27.6875	39870.00	17.16625	24719.4000
	1.19	1.1122	27.8050	40039.20	17.23910	24824.3040

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot—Continued

DIMENSIONS IN INCHES			COEFFICIENT = 1.00		COEFFICIENT = 0.62	
Diameters		Area	Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
	1.20	1.1310	28.2750	40716.00	17.5305	25243.9200
13–64	1.2031	1.1368	28.4200	40924.80	17.6204	25373.3760
	1.21	1.1499	28.7475	41396.40	17.82345	25665.9780
7–32	1.2187	1.1651	29.1275	41943.60	18.05905	26005.0320
	1.22	1.1690	29.2250	42084.00	18.1195	26092.080
	1.23	1.1882	29.7050	42775.20	18.4171	26520.624
15–64	1.2343	1.1967	29.9175	43081.20	18.54885	26710.344
	1.24	1.2076	30.1900	43473.60	18.7178	26953.632
1–4	1.2500	1.2272	30.6800	44179.20	19.0216	27391.104
	1.26	1.2469	31.1725	44888.40	19.3269	27830.808
17–64	1.2656	1.2580	31.450	45288.00	19.4990	28078.560
	1.27	1.2668	31.670	45604.80	19.6354	28274.976
	1.28	1.287	32.175	46332.00	19.9485	28725.840
9–32	1.2812	1.289	32.225	46404.00	19.9795	28770.048
	1.29	1.307	32.675	47052.00	20.2585	29172.240
19–64	1.2968	1.321	33.025	47556.00	20.4755	29484.72
	1.30	1.327	33.175	47772.00	20.5685	29618.64
	1.31	1.348	33.700	48528.00	20.8940	30087.36
5–16	1.3125	1.353	33.825	48708.00	20.9715	30198.96
	1.32	1.368	34.200	49248.00	21.2040	30533.76
21–64	1.3281	1.384	34.600	49824.00	21.4520	30890.88
	1.33	1.389	34.725	50004.00	21.5295	31002.48
	1.34	1.410	35.250	50760.00	21.8550	31471.20
11–32	1.3475	1.426	35.650	51336.00	22.1030	31828.32
	1.35	1.431	35.775	51516.00	22.1805	31939.92
23–64	1.3593	1.451	36.275	52236.00	22.4905	32386.32
	1.36	1.453	36.325	52308.00	22.5215	32430.96
	1.37	1.474	36.850	53064.00	22.8470	32899.68
3–8	1.375	1.485	37.125	53460.00	23.0175	33145.20
	1.38	1.496	37.400	53856.00	23.1880	33390.72
	1.39	1.517	37.925	54612.00	23.5135	33859.44
25–64	1.3906	1.519	37.975	54684.00	23.5445	33904.08
	1.40	1.539	38.475	55404.00	23.8545	34350.48
13–32	1.4062	1.554	38.850	55944.00	24.0870	34685.28
	1.41	1.561	39.025	56196.00	24.1955	34841.52
	1.42	1.584	39.600	57024.00	24.5520	35354.88
27–64	1.4218	1.587	39.675	57132.00	24.5985	35421.84
	1.43	1.606	40.150	57816.00	24.8930	35845.92
7–16	1.4375	1.623	40.575	58428.00	25.1565	36225.36
	1.44	1.629	40.725	58644.00	25.2495	36359.28
	1.45	1.651	41.275	59436.00	25.5905	36850.32
29–64	1.4531	1.658	41.450	59688.00	25.6990	37006.56
	1.46	1.674	41.850	60264.00	25.9470	37363.68
15–32	1.4687	1.694	42.350	60984.00	26.2570	37810.08
	1.47	1.697	42.425	61092.00	26.3035	37877.04
	1.48	1.720	43.000	61920.00	26.6600	38390.40
31–64	1.4843	1.730	43.250	62280.00	26.8150	38613.60
	1.49	1.744	43.600	62784.00	27.0320	38926.08

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot—Continued

DIMENSIONS IN INCHES		Area	COEFFICIENT = 1.00		COEFFICIENT = 0.62	
Diameters			Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
1–2	1.5000	1.767	44.175	63612.00	27.3885	39439.44
	1.51	1.791	44.775	64476.00	27.7605	39975.12
33–64	1.5156	1.804	45.100	64944.00	27.9620	40265.28
	1.52	1.815	45.375	65340.00	28.1325	40510.80
	1.53	1.839	45.975	66204.00	28.5045	41046.48
17–32	1.5312	1.841	46.025	66276.00	28.5355	41091.12
	1.54	1.863	46.575	67068.00	28.8765	41582.16
35–64	1.5468	1.879	46.975	67644.00	29.1245	41939.28
	1.55	1.887	47.175	67932.00	29.2485	42117.84
	1.56	1.911	47.775	68796.00	29.6205	42653.52
9–16	1.5625	1.917	47.925	69012.00	29.7135	42787.44
	1.57	1.936	48.400	69696.00	30.0080	43211.52
37–64	1.5781	1.957	48.925	70452.00	30.3335	43680.24
	1.58	1.961	49.025	70596.00	30.3955	43769.52
	1.59	1.986	49.650	71496.00	30.7830	44327.52
19–32	1.5937	1.995	49.875	71820.00	30.9225	44528.40
	1.60	2.011	50.275	72396.00	31.1705	44885.52
39–64	1.6093	2.034	50.850	73224.00	31.5270	45398.88
	1.61	2.036	50.900	73296.00	31.5580	45443.52
	1.62	2.061	51.525	74196.00	31.9455	46001.52
5–8	1.6250	2.074	51.950	74808.00	32.2090	46380.96
	1.63	2.087	52.175	75132.00	32.3485	46581.84
	1.64	2.112	52.800	76032.00	32.7360	47139.84
41–64	1.6406	2.114	52.850	76104.00	32.7670	47184.48
	1.65	2.138	53.450	76968.00	33.1390	47720.16
21–32	1.6562	2.154	53.850	77544.00	33.3870	48077.28
	1.66	2.164	54.100	77904.00	33.5420	48300.48
	1.67	2.190	54.750	78840.00	33.9450	48880.80
43–64	1.6718	2.195	54.875	79020.00	34.0225	48992.40
	1.68	2.217	55.425	79812.00	34.3635	49483.44
11–16	1.6875	2.236	55.900	80496.00	34.6580	49907.52
	1.69	2.243	56.075	80748.00	34.7665	50063.76
	1.70	2.270	56.750	81720.00	35.1850	50666.40
45–64	1.7031	2.278	56.950	82008.00	35.3090	50844.96
	1.71	2.297	57.425	82692.00	35.6035	51269.04
23–32	1.7187	2.320	58.000	83520.00	35.9600	51782.40
	1.72	2.324	58.100	83664.00	36.0220	51871.68
	1.73	2.351	58.775	84636.00	36.4405	52474.32
47–64	1.7343	2.362	59.050	85032.00	36.6110	52719.84
	1.74	2.378	59.450	85608.00	36.8590	53076.96
3–4	1.75	2.405	60.125	86580.00	37.2775	53679.60
	1.76	2.433	60.825	87588.00	37.7115	54304.56
49–64	1.7656	2.448	61.180	88099.00	37.9316	54621.50
	1.77	2.461	61.525	88596.00	38.1455	54929.52
	1.78	2.488	62.200	89568.00	38.5640	55532.16
25–32	1.7812	2.492	62.300	89712.00	38.6260	55621.44
	1.79	2.516	62.900	90576.00	38.9980	56157.12
51–64	1.7968	2.536	63.400	91296.00	39.3080	56603.52

Discharge in U. S. Gallons Through Circular Orifices—Constant Head One Foot—Concluded

DIMENSIONS IN INCHES		Area	COEFFICIENT = 1.00		COEFFICIENT = 0.62	
Diameters			Gallons per Minute	Gallons 24 Hours	Gallons per Minute	Gallons 24 Hours
	1.80	2.545	63.625	91620.00	39.4475	56804.40
	1.81	2.573	64.325	92628.00	39.8815	57429.36
13–16	1.8125	2.580	64.500	92880.00	39.9900	57585.60
	1.82	2.602	65.050	93672.00	40.3310	58076.64
53–64	1.8281	2.625	65.625	94500.00	40.6875	58590.00
	1.83	2.630	65.750	94680.00	40.7650	58701.60
	1.84	2.659	66.475	95724.00	41.2145	59348.88
27–32	1.8437	2.670	66.750	96120.00	41.3850	59594.40
	1.85	2.688	67.200	96768.00	41.6640	59996.16
55–64	1.8593	2.716	67.900	97776.00	42.0980	60621.12
	1.86	2.717	67.925	97812.00	42.1135	60643.44
	1.87	2.746	68.650	98856.00	42.5630	61290.72
7–8	1.8750	2.761	69.025	99396.00	42.7955	61625.52
	1.88	2.776	69.400	99936.00	43.0280	61960.32
	1.89	2.806	70.150	101016.00	43.4930	62629.92
57–64	1.8906	2.807	70.175	101052.00	43.5085	62652.24
	1.90	2.835	70.875	102060.00	43.9425	63277.20
29–32	1.9062	2.854	71.350	102744.00	44.2370	63701.28
	1.91	2.865	71.625	103140.00	44.4075	63946.80
	1.92	2.895	72.375	104220.00	44.8725	64616.40
59–64	1.9218	2.901	72.525	104436.00	44.9655	64750.32
	1.93	2.926	73.150	105336.00	45.3530	65308.32
15–16	1.9375	2.948	73.700	106128.00	45.6940	65799.36
	1.94	2.956	73.900	106416.00	45.8180	65977.92
	1.95	2.986	74.650	107496.00	46.2830	66647.52
61–64	1.9531	2.996	74.900	107856.00	46.4380	66870.72
	1.96	3.017	75.425	108612.00	46.7635	67339.44
31–32	1.9687	3.043	76.075	109548.00	47.1665	67919.76
	1.97	3.048	76.200	109728.00	47.2440	68031.36
	1.98	3.079	76.975	110844.00	47.7245	68723.28
63–64	1.9843	3.092	77.300	111312.00	47.9260	69013.44
	1.99	3.110	77.750	111960.00	48.2050	69415.20
2	2.0000	3.142	78.550	113112.00	48.7010	70129.44

Mr. Wm. G. Clark, Consulting Engineer, Toledo, O., has devised a formula for determining the velocity of flow in feet per second through pipes when the diameter of the pipe in inches and the volume of discharge in million gallons per diem are known. By transposing this formula we have arranged two other formulas to determine the diameter of the pipe in inches when the discharge in million gallons per diem and the velocity of flow in feet per second are known, and to find the discharge in million gallons per diem when the diameter of the pipe in inches and the velocity in feet per second are known. By altering the factor in the formulas thus found, we have been able to use them for determining the size of orifice required to discharge a

given volume of water in twenty-four hours, to find the volume of water discharged in twenty-four hours, or to determine the velocity of discharge in feet per second if the other two factors are known.

Mr. Clark's formula is as follows:

Let F = 283.678.

M = Million gallons discharged per 24 hours.

D = Diameter of pipe in inches.

V = Velocity of flow in feet per second.

Then $V = \frac{F \times M}{D^2}$.

Example: A pipe, 16" in diameter, discharges 4,000,000 gallons of water per diem, what is the velocity of flow in feet per second?

Solution: In this case the diameter of the pipe is 16" and $D^2 = 256$. $M = 4$, and inserting, the formula becomes $V = \frac{283.678 \times 4}{256.}$ Reducing, we have $V = 4.43$ feet per second.

The factor F = 283.678 is derived in the following manner:

$F = \frac{VD^2}{M.}$ With a 10" pipe and a velocity of 10 feet per second flow through it, the number of gallons discharged in 24 hours is seen to be 3,525,120 and therefore

$F = \frac{VD^2}{3.525120} = F = \frac{10 \times (10 \times 10)}{3.52512} =$

$F = \frac{1000}{3.52512} = F = 283.678.$

From the preceding we have arranged the second formula as follows:

$$M = \frac{D^2 \times V}{F.}$$

Example: The velocity of flow through a pipe line, 16" in diameter, is 4 feet per second, how many million gallons will be discharged in twenty-four hours?

Solution: $D^2 = 256$. $V = 4$. Inserting, the formula reads $M = \frac{256 \times 4}{283.678.}$ Reduced, we have $M = 3.609$ million gallons per diem or 3,609,000 gallons per diem.

The third formula, derived from the original, is as follows:

$$D = \sqrt{\frac{F \times M}{V.}}$$

Example: What is the size of pipe required to carry four million gallons per twenty-four hours with a velocity of two feet per second?

Solution: Substituting, the formula reads $D = \sqrt{\frac{283.678 \times 4}{2.}}$ Reducing, it becomes $D = \sqrt{567.35}$ or reduced still further, $D = 23.82$. The nearest size of standard pipe is 24", and therefore we would use a 24" pipe.

In adapting these formulas to determine either the diameter of an orifice to discharge a given flow, to find the velocity of flow through an orifice, or to ascertain the volume of discharge through an orifice, it is necessary to introduce another factor, and for this purpose we have the following:

Let F = 283.678.

M = Million gallons discharged in 24 hours.

D = Diameter of orifice in inches.

V = Velocity of flow in feet per second.

c = Coefficient of discharge.

The three forms of the formula then become:

$$V = \frac{(F \times c) \times M}{D^2.}$$

$$M = \frac{D^2 \times V}{(F \times c).}$$

$$D = \sqrt{\frac{(F \times c) \times M}{V.}}$$

Where a standard orifice, with a coefficient of 0.62 is employed, $F \times c$ becomes $283.678 \times 0.62 = 175.98$ and therefore the value of 175.98 may be substituted for $(F \times c)$ if desired. In the use of the formulas for orifices it is necessary to remember that M = Million gallons daily, and for small orifices, such as are generally dealt with by the operator, this is more than will be discharged. Therefore, for small orifices the volume of water to be found must be reduced to a fraction of M. Thus, if the volume required is only 3,456 gallons per day, this must be reduced to a fraction of a million gallons, and therefore M = 0.003456.

The following table, prepared by Mr. C. Arthur Brown, gives heads, pressures, velocities, and discharges through an orifice having an area of one square inch under coefficient of 1.00 or unity.

Fargo, N. D.

Chemical Controllers

Earl Type

Table No. 2

Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges through 1 Square Inch Orifice

Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
.005	.00216	.57	34.20	.029	1.77	2,558
.010	.00433	.80	48.00	.041	2.49	3,590
.015	.00650	.98	58.80	.050	3.05	4,398
.020	.00867	1.13	67.80	.058	3.52	5,071
.025	.01083	1.27	76.20	.065	3.95	5,700
.030	.01300	1.39	83.40	.072	4.33	6,238
.035	.01517	1.50	90.00	.077	4.67	6,732
.040	.01734	1.60	96.00	.083	4.98	7,181
.045	.01950	1.70	102.00	.088	5.29	7,629
.050	.02167	1.79	107.40	.092	5.57	8,034
.055	.02384	1.88	112.80	.097	5.85	8,437
.060	.02601	1.97	118.20	.102	6.14	8,841
.065	.02817	2.04	122.40	.105	6.35	9,156
.070	.03034	2.12	127.20	.110	6.60	9,515
.075	.03251	2.20	132.00	.114	6.85	9,874
.080	.03468	2.27	136.20	.118	7.07	10,188
.0833	.03612	2.32	139.20	.120	7.23	10,412
.085	.03685	2.34	140.40	.121	7.29	10,502
.090	.03901	2.41	144.60	.125	7.51	10,816
.095	.04118	2.47	148.20	.128	7.69	11,086
.100	.04335	2.54	152.40	.132	7.91	11,400
.105	.04552	2.60	156.00	.135	8.10	11,669
.110	.04768	2.66	159.60	.138	8.29	11,938
.115	.04985	2.72	163.20	.141	8.47	12,208
.120	.05202	2.78	166.80	.144	8.66	12,477
.125	.05419	2.84	170.40	.147	8.85	12,746
.130	.05635	2.89	173.40	.150	9.00	12,970
.135	.05852	2.95	177.00	.153	9.19	13,240
.140	.06069	3.00	180.00	.155	9.35	13,464
.145	.06286	3.05	183.00	.158	9.50	13,689
.150	.06502	3.11	186.60	.161	9.69	13,958
.155	.06719	3.16	189.60	.164	9.84	14,182
.160	.06936	3.21	192.60	.166	10.00	14,407
.165	.07153	3.26	195.60	.169	10.16	14,631
.166	.07196	3.27	196.20	.170	10.19	14,676
.170	.07370	3.31	198.60	.171	10.31	14,856
.175	.07586	3.36	201.60	.174	10.47	15,080
.180	.07803	3.40	204.00	.176	10.59	15,260
.185	.08020	3.45	207.00	.179	10.75	15,485
.190	.08237	3.50	210.00	.181	10.90	15,708
.195	.08453	3.55	213.00	.184	11.06	15,933
.200	.08670	3.59	215.40	.186	11.18	16,112
.210	.09104	3.68	220.80	.191	11.47	16,516
.220	.09537	3.76	225.60	.195	11.71	16,875
.230	.09971	3.85	231.00	.199	11.99	17,279
.250	.10404	3.93	235.80	.204	12.24	17,638
.240	.10838	4.01	240.60	.208	12.49	17,997
.260	.11271	4.09	245.40	.212	12.74	18,357
.270	.11705	4.17	250.20	.216	12.99	18,716
.280	.12138	4.25	255.00	.220	13.24	19,075
.290	.12572	4.32	259.20	.224	13.46	19,389
.300	.13005	4.39	263.40	.228	13.68	19,703

Table No. 2—Continued

Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges through 1 Square Inch Orifice

Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
.310	.13439	4.47	268.20	.232	13.93	20,062
.320	.13872	4.54	273.40	.236	14.20	20,451
.330	.14306	4.61	276.60	.239	14.36	20,691
.340	.14740	4.68	280.80	.243	14.58	21,005
.350	.15173	4.75	285.00	.246	14.80	21,319
.360	.15607	4.81	288.60	.249	14.92	21,588
.370	.16040	4.87	292.20	.252	15.17	21,858
.380	.16474	4.94	296.40	.256	15.38	22,157
.390	.16907	5.01	300.60	.260	15.61	22,486
.400	.17341	5.07	304.20	.263	15.80	22,755
.410	.17774	5.14	308.40	.267	16.02	23,069
.420	.18208	5.20	312.00	.270	16.20	23,339
.430	.18641	5.26	315.60	.273	16.39	23,608
.440	.19075	5.32	319.20	.276	16.58	23,877
.450	.19508	5.38	322.80	.279	16.76	24,147
.460	.19942	5.44	326.40	.282	16.95	24,416
.470	.20375	5.50	330.00	.285	17.14	24,685
.480	.20809	5.56	333.60	.288	17.32	24,954
.490	.21242	5.62	337.20	.291	17.51	25,224
.500	.21676	5.67	340.20	.294	17.67	25,437
.510	.22110	5.73	343.80	.297	17.85	25,718
.520	.22543	5.79	347.40	.300	18.04	25,987
.530	.22977	5.85	351.00	.303	18.23	26,256
.540	.23410	5.90	354.00	.306	18.38	26,481
.550	.23844	5.95	357.00	.309	18.54	26,705
.560	.24277	6.00	360.00	.311	18.70	26,929
.570	.24711	6.06	363.60	.314	18.88	27,199
.580	.25144	6.11	366.60	.317	19.04	27,423
.590	.25578	6.17	370.20	.320	19.23	27,692
.600	.26011	6.22	373.20	.323	19.38	27,917
.610	.26445	6.28	376.80	.326	19.57	28,186
.620	.26878	6.32	379.20	.328	19.69	28,366
.630	.27312	6.37	382.20	.330	19.85	28,590
.640	.27745	6.42	385.20	.333	20.01	28,814
.650	.28179	6.47	388.20	.336	20.16	29,039
.660	.28612	6.52	391.20	.338	20.32	29,263
.670	.29046	6.57	394.20	.341	20.47	29,488
.680	.29480	6.61	396.60	.343	20.60	29,667
.690	.29913	6.66	399.60	.345	20.75	29,892
.700	.30347	6.71	402.60	.348	20.91	30,116
.710	.30780	6.76	405.60	.351	21.07	30,340
.720	.31214	6.81	408.60	.353	21.22	30,565
.730	.31647	6.86	411.60	.356	21.38	30,799
.740	.32081	6.91	414.60	.358	21.53	31,014
.750	.32514	6.95	417.00	.361	21.66	31,193
.760	.32948	6.99	419.40	.363	21.78	31,373
.770	.33381	7.04	422.40	.365	21.94	31,597
.780	.33815	7.09	425.40	.368	22.09	31,822
.790	.34248	7.13	427.80	.370	22.22	32,001
.800	.34682	7.18	430.80	.372	22.37	32,226
.810	.35115	7.22	433.20	.375	22.50	32,405
.820	.35549	7.26	435.60	.377	22.62	32,585

Table No. 2—Continued

Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges through 1 Square Inch Orifice

Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
.830	.35982	7.31	438.60	.379	22.78	32,809
.840	.36416	7.35	441.00	.381	22.90	32,989
.850	.36850	7.40	444.00	.384	23.06	33,213
.860	.37283	7.44	446.40	.386	23.18	33,393
.870	.37717	7.48	448.80	.388	23.31	33,572
.880	.38150	7.53	451.80	.391	23.47	33,796
.890	.38584	7.57	454.20	.393	23.59	33,976
.900	.39017	7.61	456.60	.395	23.71	34,156
.910	.39451	7.65	459.00	.397	23.84	34,335
.920	.39884	7.70	462.00	.399	23.99	34,559
.930	.40318	7.74	464.40	.402	24.12	34,739
.940	.40751	7.78	466.80	.404	24.24	34,919
.950	.41185	7.82	469.20	.406	24.37	35,098
.960	.41618	7.86	471.60	.408	24.49	35,278
.970	.42052	7.90	474.00	.410	24.62	35,457
.980	.42485	7.94	476.40	.412	24.74	35,637
.990	.42919	7.98	478.80	.414	24.87	35,816
1.00	.43353	8.02	481.20	.417	25.02	36,041
1.02	.44220	8.10	486.00	.420	25.24	36,357
1.04	.45087	8.18	490.80	.424	25.49	36,714
1.06	.45954	8.26	495.60	.429	25.74	37,073
1.08	.46821	8.34	500.40	.433	25.99	37,431
1.10	.47688	8.41	504.60	.436	26.21	37,746
1.12	.48555	8.49	509.40	.441	26.46	38,105
1.14	.49422	8.57	514.20	.445	26.71	38,465
1.16	.50289	8.64	518.40	.448	26.93	38,779
1.18	.51156	8.72	523.20	.452	27.17	39,138
1.20	.52023	8.79	527.40	.456	27.39	39,452
1.22	.52890	8.87	532.20	.460	27.64	39,811
1.24	.53757	8.94	536.40	.464	27.86	40,125
1.26	.54624	9.01	540.60	.468	28.08	40,439
1.28	.55491	9.08	544.80	.471	28.30	40,753
1.30	.56358	9.15	549.00	.475	28.51	41,068
1.32	.57225	9.21	552.60	.478	28.70	41,337
1.34	.58092	9.29	557.40	.483	28.95	41,696
1.36	.58959	9.36	561.60	.486	29.17	42,010
1.38	.59826	9.43	565.80	.489	29.39	42,324
1.40	.60693	9.49	569.40	.492	29.57	42,594
1.42	.61560	9.57	574.20	.497	29.82	42,953
1.44	.62427	9.63	577.80	.500	30.01	43,222
1.46	.63294	9.70	582.00	.503	30.23	43,536
1.48	.64161	9.77	586.20	.507	30.45	43,850
1.50	.65028	9.83	589.80	.510	30.63	44,120
1.52	.65895	9.90	594.00	.514	30.85	44,434
1.54	.66762	9.96	597.60	.517	31.04	44,703
1.56	.67629	10.00	600.00	.519	31.16	44,883
1.58	.68496	10.10	606.00	.524	31.48	45,331
1.60	.69363	10.20	612.00	.529	31.79	45,780
1.65	.71530	10.30	618.00	.535	32.10	46,229
1.70	.73698	10.50	630.00	.545	32.72	47,127
1.75	.75865	10.60	636.00	.550	33.03	47,576
1.80	.78033	10.80	648.00	.561	33.66	48,473

Table No. 2—Continued

Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges through 1 Square Inch Orifice.

Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
1.85	.80201	10.90	654.00	.566	33.97	48,922
1.90	.82368	11.10	666.00	.576	34.59	49,820
1.95	.84536	11.20	672.00	.581	34.90	50,269
2.00	.86706	11.40	684.00	.592	35.53	51,166
2.10	.91041	11.70	702.00	.607	36.46	52,513
2.20	.95376	11.90	714.00	.618	37.09	53,410
2.30	.99711	12.20	732.00	.633	38.02	54,757
2.40	1.04047	12.40	744.00	.644	38.64	55,655
2.50	1.08382	12.60	756.00	.654	39.27	56,552
2.60	1.12717	12.90	774.00	.670	40.20	57,899
2.70	1.17053	13.20	792.00	.685	41.14	59,245
2.80	1.21388	13.40	804.00	.696	41.76	60,143
2.90	1.25723	13.70	822.00	.711	42.70	61,489
3.00	1.30059	13.90	834.00	.722	43.32	62,387
3.10	1.34394	14.10	846.00	.732	43.94	63,285
3.20	1.38729	14.30	858.00	.742	44.57	64,182
3.30	1.43064	14.50	870.00	.753	45.19	65,080
3.40	1.47400	14.80	888.00	.768	46.12	66,426
3.50	1.51735	15.00	900.00	.779	46.75	67,324
3.60	1.56070	15.20	912.00	.789	47.37	68,222
3.70	1.60406	15.40	924.00	.799	47.99	69,119
3.80	1.64741	15.60	936.00	.810	48.62	70,017
3.90	1.69076	15.80	948.00	.820	49.24	70,915
4.00	1.73412	16.00	960.00	.831	49.87	71,812
4.20	1.82082	16.40	984.00	.851	51.11	73,608
4.40	1.90753	16.80	1,008.00	.872	52.36	75,403
4.60	1.99423	17.20	1,032.00	.893	53.61	77,198
4.80	2.08094	17.60	1,056.00	.914	54.85	78,994
5.00	2.16765	17.90	1,074.00	.929	55.79	80,340
5.20	2.25435	18.30	1,098.00	.950	57.03	82,136
5.40	2.34106	18.70	1,122.00	.971	58.28	83,931
5.60	2.42776	19.00	1,140.00	.987	59.22	85,277
5.80	2.51447	19.30	1,158.00	1.022	60.15	86,624
6.00	2.60118	19.70	1,182.00	1.023	61.40	88,419
6.20	2.68788	20.00	1,200.00	1.038	62.33	89,766
6.40	2.77459	20.30	1,218.00	1.054	63.27	91,112
6.60	2.86129	20.60	1,236.00	1.070	64.20	92,459
6.80	2.94800	20.90	1,254.00	1.085	65.14	93,805
7.00	3.03471	21.20	1,272.00	1.101	66.07	95,152
7.20	3.12141	21.50	1,290.00	1.116	67.01	96,498
7.40	3.20812	21.80	1,308.00	1.132	67.94	97,845
7.60	3.29482	22.10	1,326.00	1.148	68.88	99,191
7.80	3.38153	22.40	1,344.00	1.163	69.81	100,538
8.00	3.46824	22.70	1,362.00	1.179	70.75	101,884
8.20	3.55494	23.00	1,380.00	1.194	71.68	103,231
8.40	3.64165	23.30	1,398.00	1.210	72.62	104,577
8.60	3.72835	23.50	1,410.00	1.220	73.24	105,475
8.80	3.81506	23.80	1,428.00	1.236	74.18	106,821
9.00	3.90177	24.10	1,446.00	1.251	75.11	108,168
9.20	3.98847	24.30	1,458.00	1.262	75.74	109,065
9.40	4.07518	24.60	1,476.00	1.277	76.67	110,412
9.60	4.16188	24.80	1,488.00	1.288	77.29	111,310

Table No. 2—Continued

Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges through 1 Square Inch Orifice

Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
9.80	4.24859	25.10	1,506.00	1.303	78.23	112,656
10.00	4.33530	25.40	1,524.00	1.319	79.16	114,003
10.50	4.55206	26.00	1,560.00	1.350	81.03	116,695
11.00	4.76883	26.60	1,596.00	1.381	82.90	119,388
11.50	4.98559	27.20	1,632.00	1.412	84.77	122,081
12.00	5.20236	27.80	1,668.00	1.444	86.64	124,774
12.50	5.41912	28.40	1,704.00	1.475	88.51	127,467
13.00	5.63589	28.90	1,734.00	1.501	90.07	129,712
13.50	5.85265	29.50	1,770.00	1.532	91.94	132,405
14.00	6.06942	30.00	1,800.00	1.558	93.50	134,649
14.50	6.28618	30.50	1,830.00	1.584	95.06	136,893
15.00	6.50295	31.10	1,866.00	1.615	96.93	139,586
15.50	6.71971	31.60	1,896.00	1.641	98.49	141,830
16.00	6.9364	32.10	1,926.00	1.667	100.05	144,074
16.50	7.1532	32.60	1,956.00	1.693	101.61	146,318
17.00	7.3700	33.10	1,986.00	1.719	103.16	148,562
17.50	7.5867	33.60	2,016.00	1.745	104.72	150,807
18.00	7.8035	34.00	2,040.00	1.766	105.97	152,602
18.50	8.0203	34.50	2,070.00	1.792	107.53	154,846
19.00	8.2370	35.00	2,100.00	1.818	109.09	157,090
19.50	8.4538	35.40	2,124.00	1.838	110.33	158,886
20.00	8.6706	35.90	2,154.00	1.864	111.89	161,130
20.50	8.8873	36.30	2,178.00	1.885	113.14	162,925
21.00	9.1041	36.80	2,208.00	1.911	114.70	165,169
21.50	9.3208	37.20	2,232.00	1.932	115.94	166,965
22.00	9.5376	37.60	2,256.00	1.953	117.19	168,760
22.50	9.7544	38.10	2,286.00	1.979	118.75	171,004
23.00	9.9711	38.50	2,310.00	1.999	119.99	172,799
23.50	10.1879	38.90	2,334.00	2.020	121.24	174,595
24.00	10.4047	39.30	2,358.00	2.041	122.49	176,390
24.50	10.6214	39.70	2,382.00	2.062	123.74	178,185
25.00	10.8382	40.10	2,406.00	2.083	124.98	179,981
26.00	11.2717	40.90	2,454.00	2.124	127.48	183,571
27.00	11.7053	41.70	2,502.00	2.166	129.97	187,162
28.00	12.1388	42.50	2,550.00	2.207	132.46	190,753
29.00	12.5723	43.20	2,592.00	2.244	134.64	193,894
30.00	13.0059	43.90	2,634.00	2.280	136.83	197,036
31.00	13.4394	44.70	2,682.00	2.322	139.32	200,627
32.00	13.8729	45.40	2,724.00	2.358	141.50	203,769
33.00	14.3064	46.10	2,766.00	2.394	143.68	206,910
34.00	14.7400	46.70	2,802.00	2.425	145.55	209,603
35.00	15.1735	47.40	2,844.00	2.462	147.74	212,745
36.00	15.6070	48.10	2,886.00	2.498	149.92	215,887
37.00	16.0406	48.80	2,928.00	2.535	152.10	219,029
38.00	16.4741	49.50	2,970.00	2.571	154.28	222,171
39.00	16.9076	50.10	3,006.00	2.602	156.15	224,864
40.00	17.3412	50.70	3,042.00	2.633	158.02	227,557
41.00	17.7747	51.30	3,078.00	2.664	159.89	230,250
42.00	18.2082	52.00	3,120.00	2.701	162.07	233,391
43.00	18.6417	52.60	3,156.00	2.732	163.94	236,084
44.00	19.0753	53.20	3,192.00	2.763	165.81	238,777
45.00	19.5088	53.80	3,228.00	2.794	167.68	241,470

Table No. 2—Continued

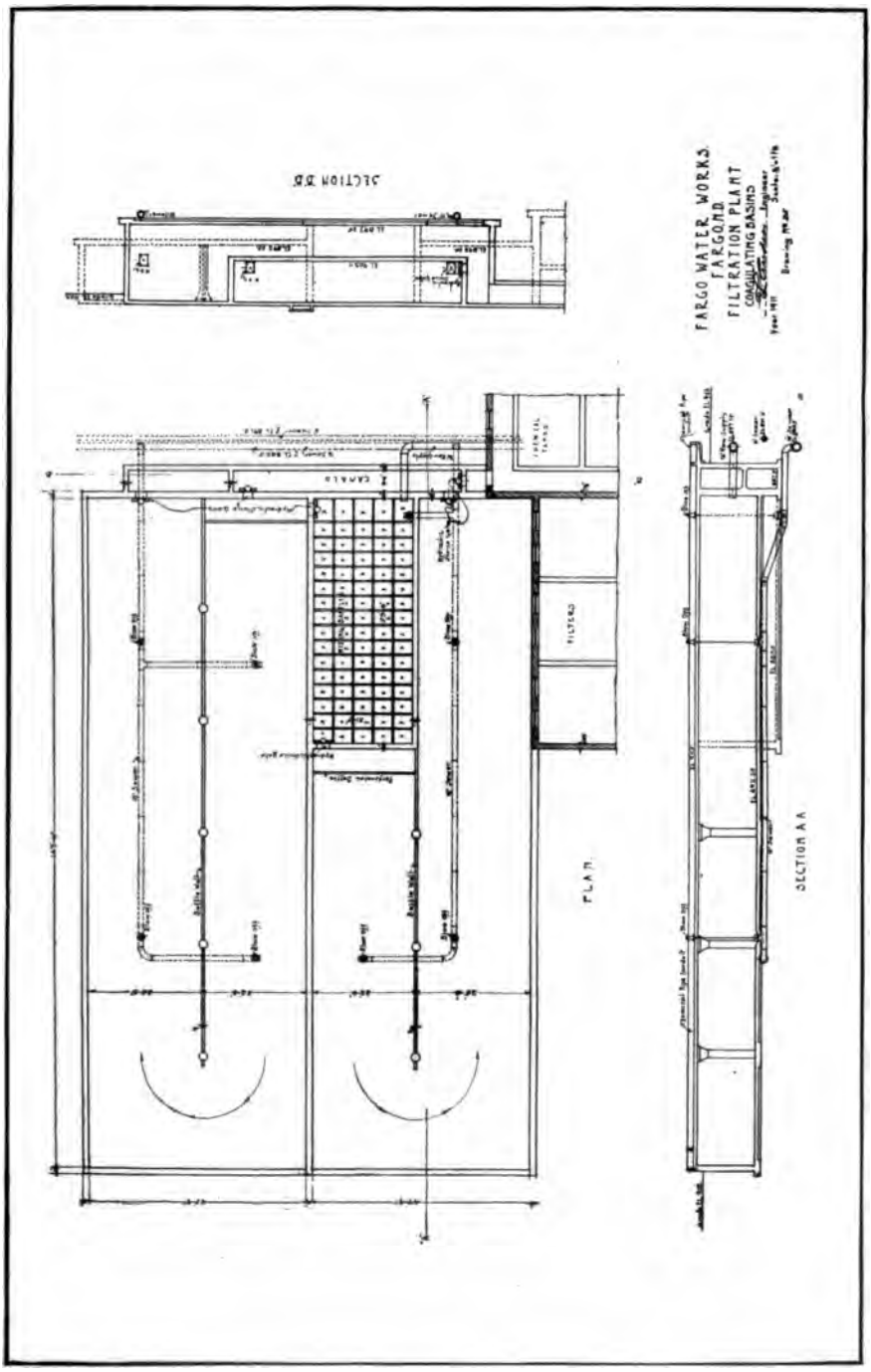
Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges through 1 Square Inch Orifice.

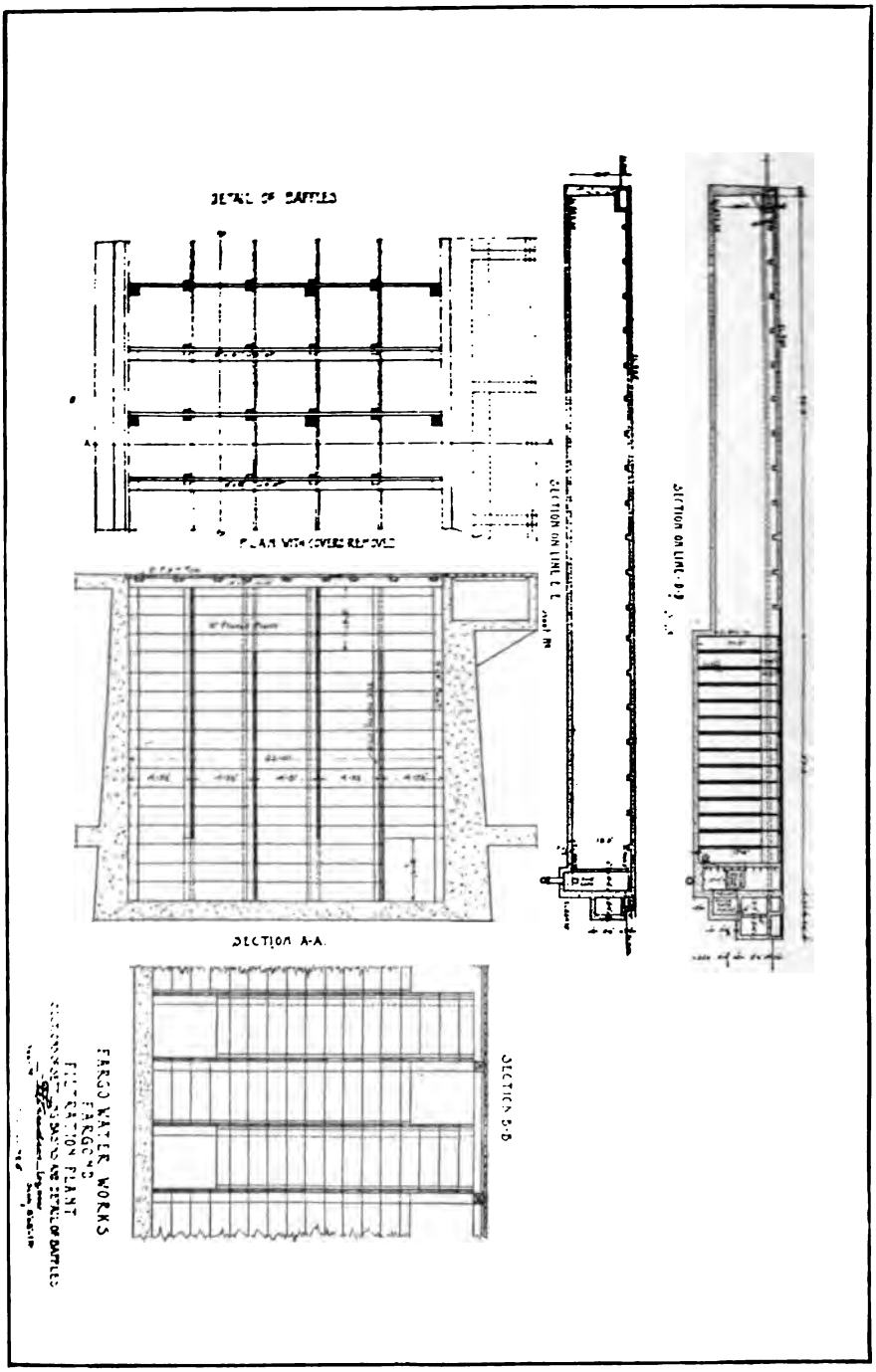
Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
46.00	19.9423	54.40	3,264.00	2.825	169.55	244,163
47.00	20.3759	55.00	3,300.00	2.857	171.42	246,856
48.00	20.8094	55.60	3,336.00	2.889	173.29	249,549
49.00	21.2429	56.20	3,372.00	2.919	175.16	252,242
50.00	21.6765	56.70	3,402.00	2.945	176.72	254,487
51.00	22.1100	57.30	3,438.00	2.976	178.59	257,180
52.00	22.5435	57.80	3,468.00	3.002	180.15	259,424
53.00	22.9770	58.40	3,504.00	3.033	182.02	262,117
54.00	23.4106	59.00	3,540.00	3.064	183.89	264,810
55.00	23.8441	59.50	3,570.00	3.090	185.45	267,054
56.00	24.2776	60.00	3,600.00	3.116	187.01	269,298
57.00	24.7112	60.60	3,636.00	3.148	188.88	271,991
58.00	25.1447	61.10	3,666.00	3.174	190.44	274,235
59.00	25.5782	61.60	3,696.00	3.199	191.99	276,479
60.00	26.0118	62.10	3,726.00	3.225	193.55	278,723
61.00	26.4453	62.70	3,762.00	3.257	195.42	281,416
62.00	26.8788	63.20	3,792.00	3.283	196.98	283,661
63.00	27.3123	63.70	3,822.00	3.309	198.54	285,905
64.00	27.7459	64.20	3,852.00	3.335	200.10	288,149
65.00	28.1794	64.70	3,882.00	3.361	201.66	290,393
66.00	28.6129	65.20	3,912.00	3.387	203.22	292,637
67.00	29.0465	65.70	3,942.00	3.412	204.77	294,881
68.00	29.4800	66.20	3,972.00	3.438	206.33	297,125
69.00	29.9135	66.70	4,002.00	3.464	207.89	299,370
70.00	30.3471	67.10	4,026.00	3.485	209.14	301,165
71.00	30.7806	67.60	4,056.00	3.511	210.70	303,409
72.00	31.2141	68.10	4,086.00	3.537	212.25	305,653
73.00	31.6476	68.50	4,110.00	3.558	213.50	307,449
74.00	32.0812	69.00	4,140.00	3.584	215.06	309,693
75.00	32.5147	69.50	4,170.00	3.610	216.62	311,937
76.00	32.9482	69.90	4,194.00	3.631	217.86	313,732
77.00	33.3818	70.40	4,224.00	3.657	219.42	315,976
78.00	33.8153	70.90	4,254.00	3.683	220.98	318,220
79.00	34.2488	71.30	4,278.00	3.703	222.23	320,016
80.00	34.6824	71.80	4,308.00	3.729	223.79	322,260
81.00	35.1159	72.20	4,332.00	3.750	225.03	324,055
82.00	35.5494	72.60	4,356.00	3.771	226.28	325,851
83.00	35.9829	73.10	4,386.00	3.797	227.84	328,095
84.00	36.4165	73.50	4,410.00	3.818	229.09	329,890
85.00	36.8500	74.00	4,440.00	3.844	230.64	332,134
86.00	37.2835	74.40	4,464.00	3.864	231.89	333,930
87.00	37.7171	74.80	4,488.00	3.885	233.14	335,725
88.00	38.1506	75.30	4,518.00	3.911	234.70	337,969
89.00	38.5841	75.70	4,542.00	3.932	235.94	339,764
90.00	39.0177	76.10	4,566.00	3.953	237.19	341,560
91.00	39.4512	76.50	4,590.00	3.974	238.44	343,355
92.00	39.8847	76.90	4,614.00	3.994	239.68	345,150
93.00	40.3182	77.40	4,644.00	4.020	241.24	347,394
94.00	40.7518	77.80	4,668.00	4.041	242.49	349,190
95.00	41.1853	78.20	4,692.00	4.062	243.74	350,985
96.00	41.6188	78.60	4,716.00	4.083	244.98	352,780
97.00	42.0524	79.00	4,740.00	4.103	246.23	354,576

Table No. 2—Concluded

Table of Water Heads, Equivalent Pressures, Theoretical Velocities, Theoretical Discharges, through 1 Square Inch Orifice

Head in Feet	Equivalent Pressure Pounds per Sq. Inch	Theoretical Velocity Ft. per Second	Theoretical Velocity Ft. per Minute	Theoretical Discharge Gals. per Second	Theoretical Discharge Gals. per Minute	Theoretical Discharge Gals. per Diem
98.00	42.4859	79.40	4,764.00	4.124	247.48	356,371
99.00	42.9194	79.80	4,788.00	4.145	248.72	358,166
100.00	43.3530	80.30	4,818.00	4.171	250.28	360,411
125.00	54.1912	89.70	5,382.00	4.659	279.58	402,601
150.00	65.0295	98.30	5,898.00	5.106	306.38	441,200
175.00	75.8677	106.00	6,360.00	5.506	330.38	475,760
200.00	86.7060	114.00	6,840.00	5.922	355.32	511,667
225.00	97.5442	120.00	7,200.00	6.233	374.02	538,596
250.00	108.382	126.00	7,560.00	6.545	392.72	565,526
275.00	119.220	133.00	7,980.00	6.909	414.54	596,944
300.00	130.059	139.00	8,340.00	7.220	433.24	623,874
350.00	151.735	150.00	9,000.00	7.792	467.53	673,246
400.00	173.412	160.00	9,600.00	8.311	498.70	718,129
450.00	195.088	170.00	10,200.00	8.831	529.86	763,012
500.00	216.765	179.00	10,740.00	9.298	557.92	803,406
550.00	238.441	188.00	11,280.00	9.766	585.97	843,801
600.00	260.118	197.00	11,820.00	10.233	614.02	884,196
700.00	303.471	212.00	12,720.00	11.012	660.77	951,521
800.00	346.824	227.00	13,620.00	11.758	707.53	1,018,845
900.00	390.177	241.00	14,460.00	12.519	751.16	1,081,682
1,000.00	433.530	254.00	15,240.00	13.194	791.68	1,140,030


FARGO WATER WORKS
FARGO, N.D.
FILTRATION PLANT
COAGULATING BASINS
SECTION B-B
PLAN
SECTION A-A


DETAIL OF BAFFLES
SECTION A-A.
SECTION B-B.
FARGO WATER WORKS
FARGO, N.D.
FILTRATION PLANT

The following table gives the equivalents of million gallons in cubic feet; also the flows per minute and second in cubic feet and gallons when the flow is distributed evenly over 24 hours.

Table No. 3

PER 24 HOURS		FLOW EQUIVALENTS			
Million Gallons	Cubic Feet Equivalent	Cubic Feet per Minute	Cubic Feet per Second	U. S. Gallons per Minute	U. S. Gallons per Second
1	133,680.55	92.88	1.5481	694.44	11.57
2	267,361.11	185.77	3.09	1,388.88	23.14
3	401,041.67	278.66	4.64	2,083.33	34.72
4	534,722.22	371.55	6.19	2,777.77	46.29
5	668,402.78	464.44	7.74	3,472.22	57.87
6	802,083.34	557.33	9.28	4,166.66	69.44
7	935,763.89	650.22	10.83	4,861.11	81.01
8	1,069,444.45	743.11	12.38	5,555.55	92.59
9	1,203,125.01	836.00	13.93	6,249.99	104.16
10	1,336,805.56	928.89	15.48	6,944.44	115.74
11	1,470,486.12	1,021.78	17.02	7,638.88	127.31
12	1,604,166.68	1,114.67	18.57	8,333.33	138.88
13	1,737,847.24	1,207.56	20.12	9,027.77	150.46
14	1,871,527.79	1,300.44	21.67	9,722.22	162.03
15	2,005,208.35	1,393.33	23.22	10,416.66	173.61
16	2,138,888.91	1,486.22	24.77	11,111.11	185.18
17	2,272,569.46	1,579.11	26.31	11,805.55	196.75
18	2,406,250.02	1,672.00	27.86	12,499.99	208.33
19	2,539,930.58	1,764.89	29.41	13,194.44	219.90
20	2,673,611.13	1,857.78	30.96	13,888.88	231.48
21	2,807,291.69	1,950.67	32.51	14,583.33	243.05
22	2,940,972.25	2,043.56	34.05	15,277.77	254.62
23	3,074,652.81	2,136.45	35.60	15,972.22	266.20
24	3,208,333.36	2,229.34	37.15	16,666.66	277.77
25	3,342,013.92	2,322.23	38.70	17,361.11	289.35
26	3,475,694.48	2,415.12	40.25	18,055.55	300.92
27	3,609,375.03	2,508.01	41.80	18,749.99	312.49
28	3,743,055.59	2,600.89	43.34	19,444.44	324.07
29	3,876,736.15	2,693.78	44.89	20,138.88	335.64
30	4,010,416.70	2,786.66	46.44	20,833.33	347.22
31	4,144,097.26	2,879.56	47.99	21,527.77	358.79
32	4,277,777.82	2,972.45	49.54	22,222.22	370.37
33	4,411,458.38	3,065.34	51.08	22,916.66	381.94
34	4,545,138.93	3,158.23	52.63	23,611.11	393.51
35	4,678,819.49	3,251.12	54.18	24,305.55	405.09
36	4,812,500.05	3,344.01	55.73	24,999.99	416.66
37	4,946,180.60	3,436.90	57.28	25,694.44	428.24
38	5,079,861.16	3,429.79	58.82	26,388.88	439.81
39	5,213,541.72	3,622.68	60.37	27,083.33	451.38
40	5,347,222.27	3,715.57	61.92	27,777.77	462.96
41	5,480,902.83	3,808.46	63.47	28,472.22	474.53
42	5,614,583.39	3,901.49	65.02	29,166.66	486.11
43	5,748,263.95	3,994.23	66.57	29,861.11	497.68
44	5,881,944.50	4,087.12	68.11	30,555.55	509.25
45	6,015,625.06	4,180.01	69.66	31,249.99	520.83
46	6,149,305.62	4,272.90	71.21	31,944.44	532.40
47	6,282,986.17	4,365.79	72.76	32,638.88	543.98

Table No. 3—Continued

PER 24 HOURS		FLOW EQUIVALENTS			
Million Gallons	Cubic Feet Equivalent	Cubic Feet per Minute	Cubic Feet per Second	U. S. Gallons per Minute	U. S. Gallons per Second
48	6,416,666.73	4,458.68	74.31	33,333.33	555.55
49	6,550,347.29	4,551.57	75.85	34,027.77	567.12
50	6,684,027.84	4,644.46	77.40	34,722.22	578.70
51	6,817,708.40	4,737.35	78.95	35,416.66	590.27
52	6,951,388.96	4,830.24	80.50	36,111.11	601.85
53	7,085,069.52	4,923.13	82.05	36,805.55	613.42
54	7,218,750.07	5,016.02	83.60	37,499.99	624.99
55	7,352,430.63	5,108.91	85.14	38,194.44	636.57
56	7,486,111.19	5,201.79	86.69	38,888.88	648.14
57	7,619,791.74	5,294.68	88.24	39,583.33	659.72
58	7,753,472.30	5,387.57	89.79	40,277.77	671.29
59	7,887,152.86	5,480.46	91.34	40,972.22	682.87
60	8,020,833.41	5,573.35	92.88	41,666.66	694.44
61	8,154,513.97	5,666.24	94.43	42,361.11	706.01
62	8,288,194.53	5,759.13	95.98	43,055.55	717.59
63	8,421,875.09	5,852.02	97.53	43,749.99	729.16
64	8,555,555.64	5,944.91	99.08	44,444.44	740.74
65	8,689,236.20	6,037.80	100.63	45,138.88	752.31
66	8,822,916.76	6,130.69	102.17	45,833.33	763.88
67	8,956,597.31	6,223.58	103.72	46,527.77	775.46
68	9,090,277.87	6,316.47	105.27	47,222.22	787.03
69	9,223,958.43	6,409.36	106.82	47,916.66	798.61
70	9,357,638.98	6,502.24	108.37	48,611.11	810.18
71	9,491,319.54	6,595.13	109.91	49,305.55	821.75
72	9,625,000.10	6,688.02	111.46	49,999.99	833.33
73	9,758,680.66	6,780.91	113.01	50,694.44	844.90
74	9,892,361.21	6,873.80	114.56	51,388.88	856.48
75	10,026,041.77	6,966.69	116.11	52,083.33	868.05
76	10,159,722.33	7,059.58	117.65	52,777.77	879.62
77	10,293,402.88	7,152.47	119.20	53,472.22	891.20
78	10,427,083.44	7,245.36	120.75	54,166.66	902.77
79	10,560,764.00	7,338.25	122.30	54,861.11	914.35
80	10,694,444.55	7,431.14	123.85	55,555.55	925.92
81	10,828,125.11	7,524.03	125.40	56,249.99	937.49
82	10,961,805.67	7,616.92	126.94	56,944.44	949.07
83	11,095,486.23	7,709.80	128.49	57,638.88	960.64
84	11,229,166.78	7,802.69	130.04	58,333.33	972.22
85	11,362,847.34	7,895.58	131.59	59,027.77	983.79
86	11,496,527.90	7,988.47	133.14	59,722.22	995.37
87	11,630,208.45	8,081.36	134.68	60,416.66	1,006.94
88	11,763,889.01	8,174.25	136.23	61,111.11	1,018.51
89	11,897,569.57	8,267.14	137.78	61,805.55	1,030.09
90	12,031,250.12	8,360.03	139.33	62,499.99	1,041.66
91	12,164,930.68	8,452.92	140.88	63,194.44	1,053.24
92	12,298,611.24	8,545.81	142.43	63,888.88	1,064.81
93	12,432,291.80	8,636.70	143.97	64,583.33	1,076.38
94	12,565,972.35	8,731.59	145.52	65,277.77	1,087.96
95	12,699,652.91	8,824.48	147.07	65,972.22	1,099.53
96	12,833,333.47	8,917.37	148.62	66,666.66	1,111.11
97	12,967,014.02	9,010.25	150.17	67,361.11	1,122.68
98	13,100,694.58	9,103.14	151.71	68,055.55	1,134.25
99	13,234,375.14	9,196.03	153.26	68,750.00	1,145.83
100	13,368,055.69	9,288.92	154.81	69,444.44	1,157.40

Table No. 2 is based on a coefficient of discharge of unity. Any given discharge will therefore have to be multiplied by .62 to obtain the real discharge through a standard orifice having an area of one square inch. In order to ascertain the discharge for any standard orifice of a different area, the area in square inches must first be found and noted. This may be obtained from the Table No. 1, or if not found there it may be calculated. The discharge for the given head, found in Table No. 2, must first be multiplied by .62, and the result multiplied by the area of the desired orifice in square inches. In this way the discharge for any size standard orifice under any head may be readily ascertained either for the minute or for the day, and this information enables an operator to tell, with a fair degree of accuracy, how long it will take to empty a solution tank of known capacity with any given size of orifice working under any given head.

Formulas

In order to arrive at a solution of any phase of this matter we give herewith three simple formulas which will enable the operator to work out any necessary solution.

Let A = the average number of gallons, pumped in 24 hours, and recorded as million gallons or fraction thereof.

Let G = the grains per gallon of chemical required.

Let C = the charge of chemicals required for 24 hours, in pounds.

Let P = 143 (One grain per gallon, g. p. g., equals 143 pounds per one million gallons.)

Then,

(1) $C = AGP.$ (2) $A = \frac{C}{GP}.$

(3) $G = \frac{C}{AP}.$

Examples.

(1)

A plant pumps an average of 4,280,000 gallons per 24 hours and it is desired to apply 1.54 g. p. g. of chemical treatment to the raw water, how large a charge of chemicals will be required to run the plant for twenty four hours?

Solution. In this case A = 4.28, G = 1.54 and P = 143, while the formula which applies is seen to be (1) or C = AGP. Hence we have, by substitution, the following, $C = 4.28 \times 1.54 \times 143 = C = 942.54$ pounds. Therefore if 942.54 pounds of chemicals be applied to 4,280,000 gallons of water each gallon will receive 1.54 grains.

(2)

A plant uses 942.54 pounds of chemicals per twenty-four hours and applies 1.54 g. p. g. of chemical treatment. It is desired to know what the pumpage amounts to.

Solution. In this case C = 942.54, G = 1.54 and P = 143, while the formula which applies is seen to be (2) or A = C/GP. Hence, by substitution, we have the following, $A = 942.54 \div (1.54 \times 143) = A = 4.28$

million gallons or 4,280,000 gallons. Therefore, if a plant uses a chemical charge of 942.54 pounds of chemicals at the rate of 1.54 grains per gallon, the quantity of water pumped is 4,280,000 gallons.

(3)

A plant purifies 4,280,000 gallons of water per 24 hours and uses a chemical charge of 942.54 pounds. It is desired to know how many grains per gallon of chemical treatment has been applied.

Solution. In this case C = 942.54, A = 4.28 and P = 143, while the formula which applies is seen to be G = C/AP. Hence, by substitution, we have the following, G = 942.54 ÷ (4.28 × 143) = G = 1.54 g. p. g. Therefore, if a plant purifies 4,280,000 gallons per day and uses 942.54 pounds of chemicals, the chemical treatment has been at the rate of 1.54 grains per gallon.

In order to determine what size of standard orifice will be required to empty a tank having a known capacity in gallons, under a given head and with a coefficient of discharge of .62 in twenty-four hours, refer to the Table No. 2, and under the given head find the discharge in gallons per twenty-four hours with a one square inch orifice. Multiply this by .62 and divide the capacity of the tank in gallons by the result. The quotient will be the area of the required orifice in square inches. Table No. 1 of areas will give the nearest diameter of the required orifice in inches.

Example

Example. What size of standard circular orifice, having a coefficient of discharge of .62, will be required to empty a tank holding 1100 gallons, under a constant head of one foot over the orifice, in a time period of twenty-four hours?

Solution. From Table No. 2, we obtain 36,041 gallons as the discharge for an orifice having an area of 1 sq. in. for 24 hours, under a one-foot head and a coefficient of discharge of 1.00. With a coefficient of .62 we have $36{,}041 \times .62 = 22{,}345$ gallons per diem and $\frac{1100}{22345} = .0492$ or the area of the required orifice. From the Table No. 1, we find a ¼-inch orifice has an area of .0491 square inch and delivers 1095.9 gallons per day under one foot head. Therefore it would be the orifice selected. The result calculated from Table No. 2 is shown as checking the result given by Table No. 1.

In order to calibrate an orifice of given size, under constant head of one foot, discharging from a reservoir or tank,

Let D = the drop in inches per minute.

Let A = area of tank in inches.

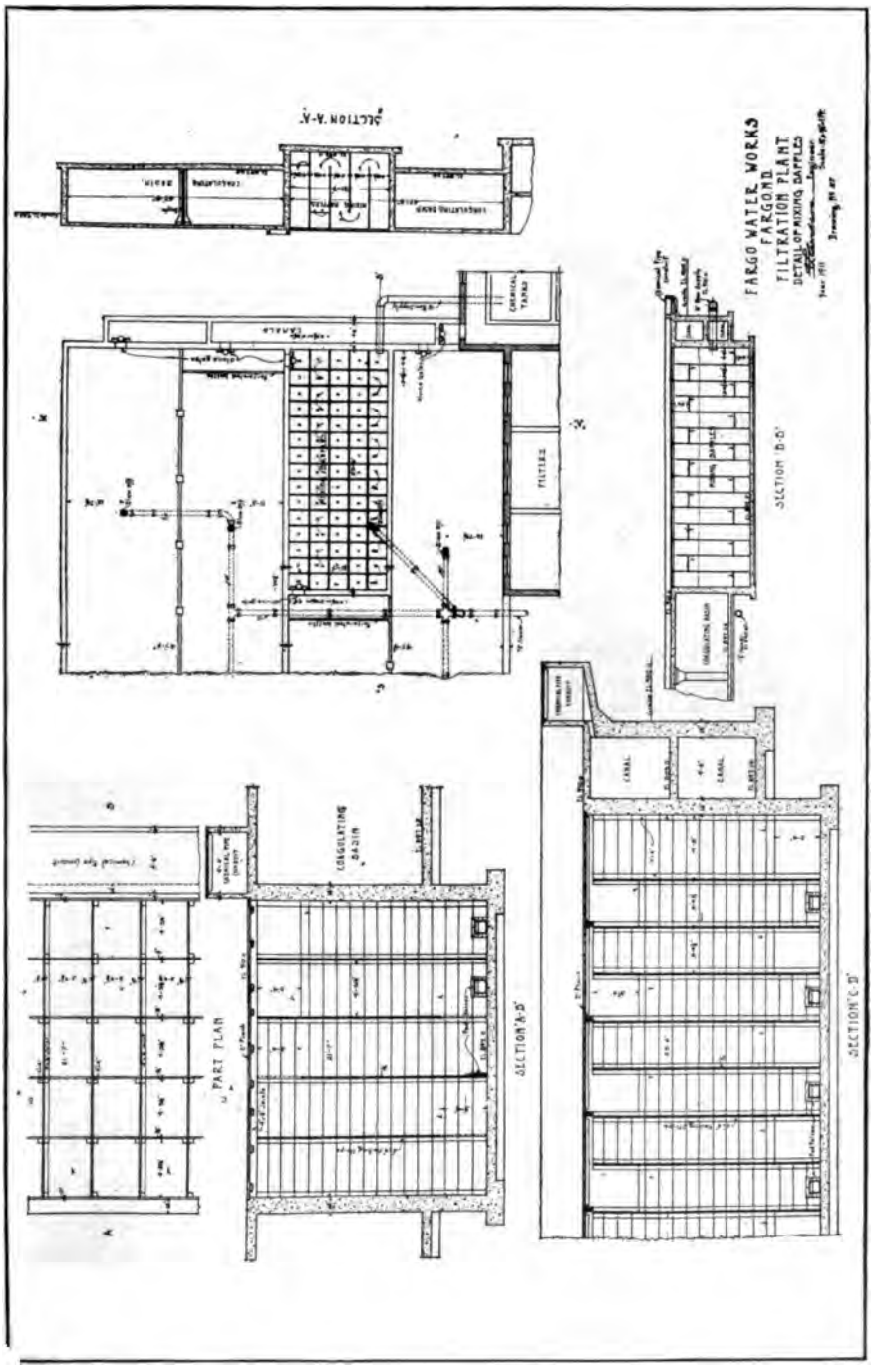
Let G = gallons per twenty-four hours.

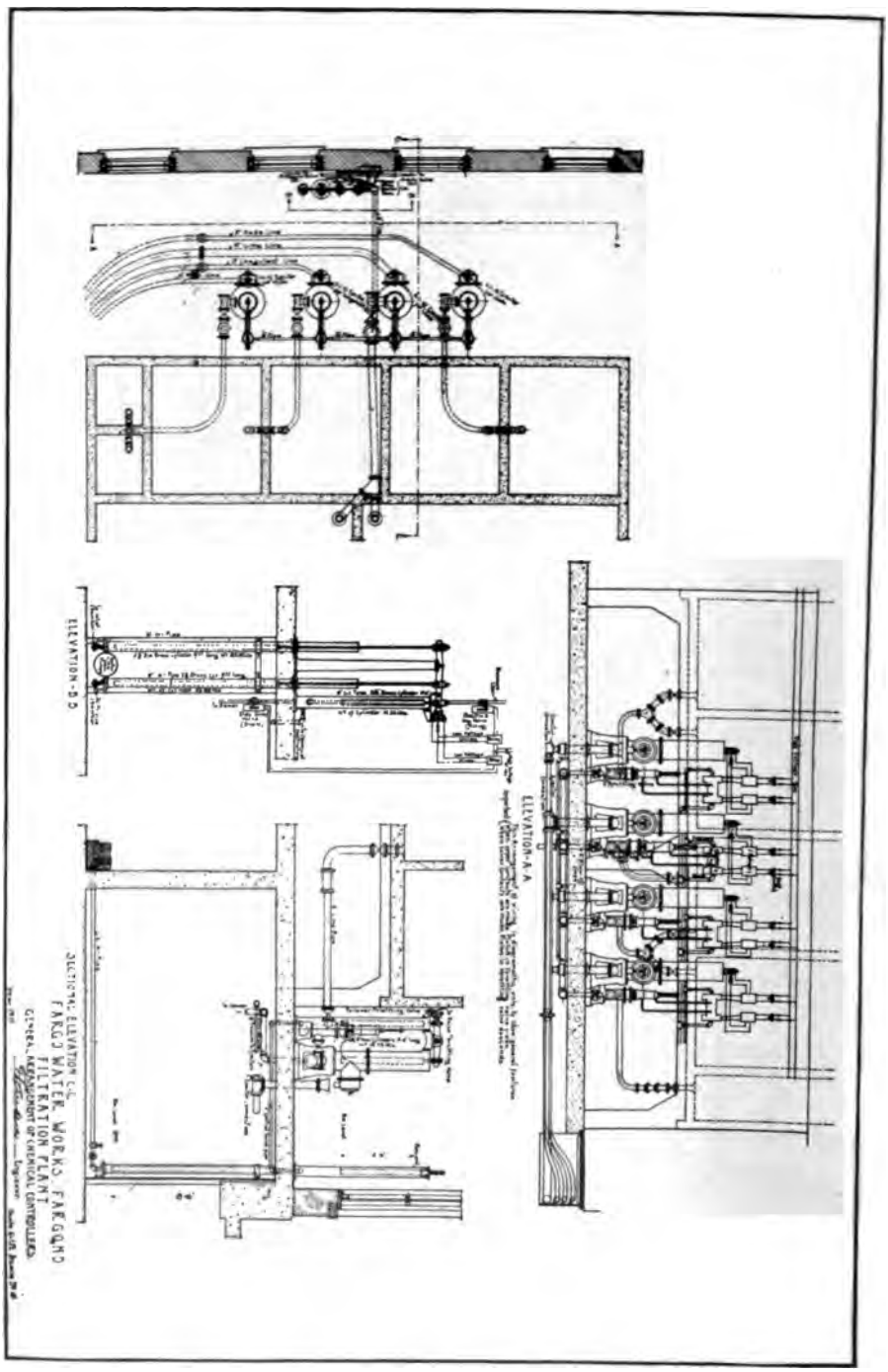
231 = cu. in. in U. S. gallon and 1440 minutes in a day.

Then $\frac{A}{231} \times D \times 1440 = G.$

Example

Example. A tank having an area of 6252.33 square inches has a


FARGO WATER WORKS
FARGOND
FILTRATION PLANT
DETAIL OF MIXING BAFFLES
SECTION A-A'
SECTION B-B'
SECTION C-D'
SECTION E-F
PART PLAN
COAGULATING BASIN
FILTERS


ELEVATION-B-B
ELEVATION-A-A
FARGO WATER WORKS FARGO
FILTRATION PLANT

of .11 inch per minute with a discharge occurring through an orifice, having a diameter of ½ inch, with a constant head of one foot over the orifice, what is the coefficient of discharge for the orifice?

The orifice has an area of .1963 square inch, and

$$\frac{6252.33}{231} \times .11 \times 1440 = 4287.3$$

or gallons per twenty-four hours discharged through orifice. Up to this point the procedure is merely that of calculating the discharge in gallons from a tank of known area with a known drop of level per minute. From Table No. 2 we find the discharge through an orifice having an area of one square inch to be 36,041 gallons per diem under a one-foot head and coefficient of 1.00, and under the same conditions an orifice having an area of .1963 would discharge $36{,}041 \times .1963 = 7074.84$ gallons per diem. In order to obtain the coefficient of discharge we divide the amount actually discharged through the orifice by theoretical discharge under a coefficient of 1.00 or $4287.3 \div 7074.84 = .6059$ or coefficient of discharge.

Hook Gauge

The method of obtaining the drop in level in the tank is to use a point gauge. This consists of two or more points accurately placed a known distance apart. All points are immersed, and when the first point touches the surface the time is taken very accurately. When he next point shows the time is again taken and the drop in inches per minute can be calculated.

In the preceding pages we have dealt rather fully with liquid flows and given the subject more space than it apparently demands. The reason for this is to be found in the number of questions which are asked by operators as to how they may figure these problems and be sure they are correct in the results. The number of inquiries and the variety of their forms in relation to this subject justifies us in believing this information to be of sufficient importance to warrant the space.

Working Conditions

Now, let us consider a case where the foregoing calculations have been worked out and take working conditions as they really occur in practice. A plant filtering 4,280,000 gallons per diem has a high rate of pumpage during the hours from 8.00 A.M. to 10.00 A.M. and from 6.00 P.M. to 8.00 P.M., amounting to an average peak load during these hours of what would correspond to a rate of 6,017,000 gallons per twenty-four hours, and a minimum rate during the hours from 12.30 A.M. to 4.30 A.M. of only 1,020,000 gallons. This corresponds to 4,180 gallons per minute for maximum rate, 2,970 gallons for average rate, and 847 gallons for a minimum rate.

Errors

During the four hours of the two peak load periods the head tank

continues to apply enough chemicals to treat 2,970 gallons per minute with 1.54 grains per gallon, but as the plant is handling 4,180 gallons during the four hours referred to, the rate per gallon of chemical treatment applied really falls to 1.09 grains per gallon.

Similarly, the same amount of chemicals applied during the hours of minimum pumpage means that each gallon, instead of receiving 1.54 grains, is really being treated at the rate of 5.40 grains per gallon for four hours.

Wastefulness

Thus the calculations to apply 1.54 grains per gallon fail. Unless the operator can know at what rate the plant is working, and unless he be conscientious enough to change the rate of chemical application with each change of flow into the plant, this must continue to occur. It is very obvious that if 1.09 grains per gallon produces the desired results, it is a very great waste to apply 1.54 grains or still worse, to apply 5.40 grains per gallon.

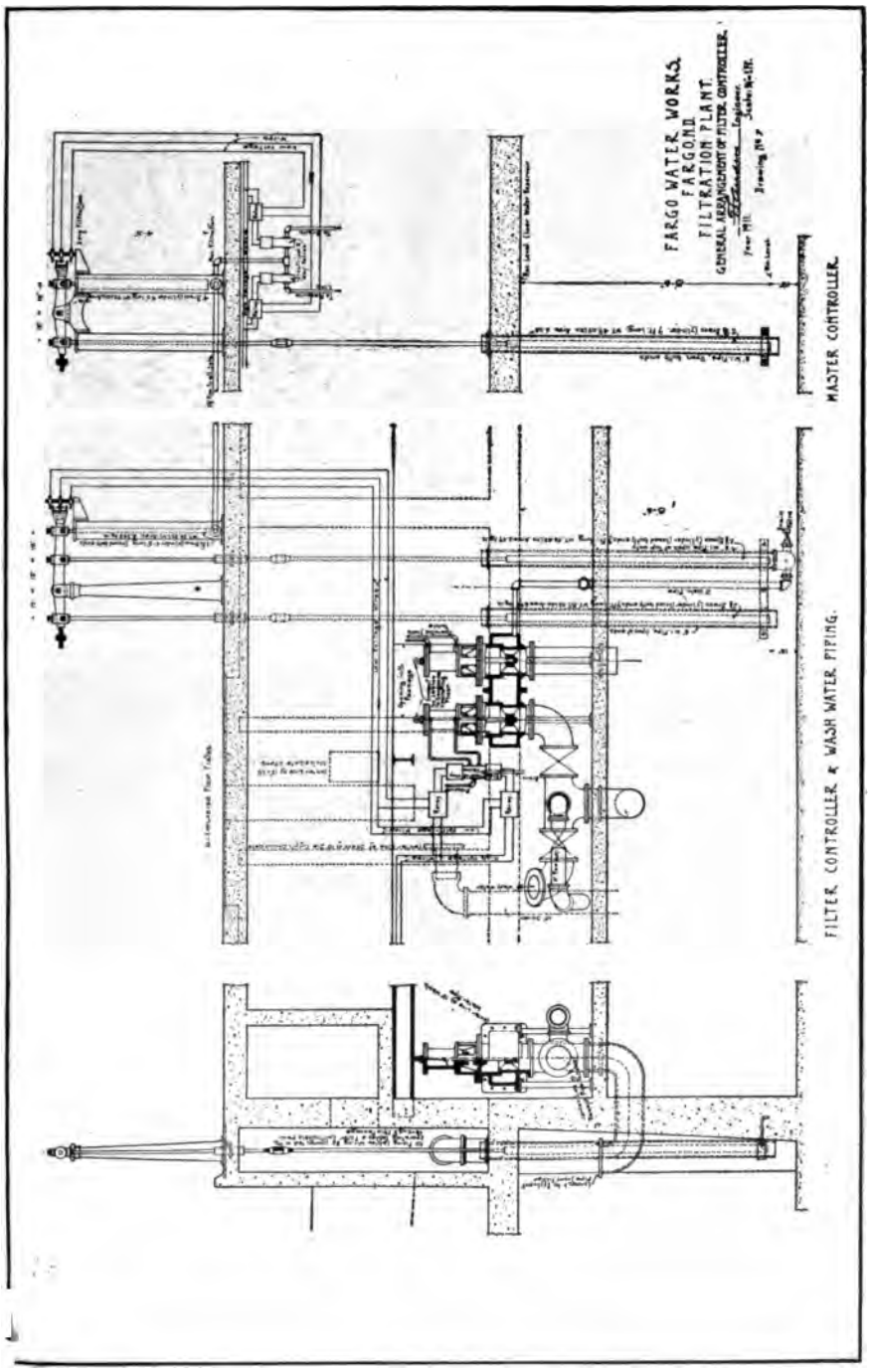
Most of the smaller plants, like the one referred to, have no device to show the operator the rate at which water is entering, and hence he cannot change the rate of chemical application with any degree of assurance. Even if he could do so, it is doubtful if many of them would, and it is a certainty that most of them would not.

Flow Recorders

However, every plant should be provided with a rate recorder which will record, indicate and integrate the flow into the plant during every minute of the day and night, and each chemical tank should be equipped with a similar device to show that the rate of chemical application has been changed to meet the changing conditions of raw water flow into the plant. If the equipment is provided, the operator can be checked and made to pay closer attention to this very important matter. The difficulty may be, and should be, overcome by devices which will not only record the variations of raw water and chemical flows, but in addition they should be such as to automatically vary the application of chemicals in strict accord with the variations of raw water flow.

Chemical Controllers

Two types of these devices may be had. One is a type that maintains a constant head over an orifice but varies the size of the chemical orifice automatically and proportionally as the rate of flow of raw water into the plant increases or decreases. The other has a fixed orifice, but varies the head over the orifice automatically and proportionally, and therefore varies the rate of applying the chemicals functionally and proportionally to changing rates of flow of the raw wa[illegible] These devices are a great advance over the older ones using a fixed


FARGO WATER WORKS.
FARGO, N.D.
FILTRATION PLANT.
GENERAL ARRANGEMENT OF FILTER CONTROLLER.
MASTER CONTROLLER.
FILTER, CONTROLLER & WASH WATER PIPING.

View Across Filters

Fargo

Chemical Preparation Room

rate of chemical flow, and should be much more generally used.

The control of the chemical treatment is one of the most difficult problems encountered and these two very satisfactory solutions will probably come into general use as soon as their value is appreciated more thoroughly by the designing engineers.

Chemicals—Where Applied

The next step is the introduction of the sulphate of iron into the water. The first question arising is, Where shall it be applied? Shall it go into the water at the same time as the lime, or should it precede or follow the application of the lime?

The real answer lies in the fact that different waters and plants require different methods of treatment. In some plants it is the part of wisdom to apply the iron before the lime, in others after the lime. In waters containing much organic matter or color, it is advantageous to apply the lime first. Where there is little color or organic matter, the iron should be introduced before the lime. Under some conditions this general rule may be rendered impractical, due to the design of the plant. In places where the iron is to be introduced before the lime, it is advisable to do so at as early a stage as possible, and to follow with the lime some distance apart.

Incrustation

Lime should never be added to water passing through a pump or a closed conduit. If an open conduit is available, it will do no harm to add the lime to the water therein, if it does not pass through a pump or closed conduit later on and preceding filtration. The reason for this is that a mixture of water and caustic lime cannot be passed through a closed conduit without causing incrustation. This incrustation may become so thick as to materially reduce the open cross section of the pipe and increase the friction beyond practical limits.

Caustic Lime

Caustic lime reaches the market in two conditions. Quick lime or lump lime comes in various sized lumps from a kiln in which it is burnt, and when cold usually differs but little if any in appearance from the rock from which it was burnt. If the stone was coarse or fine grained, the lime will be coarse or fine grained. Fat limes, in the parlance of the lime burner, are limes rich in lime and poor in magnesia, while a lean lime is higher in magnesia and lower in lime. A fat lime should contain 98 per cent. of calcium oxide with 2 per cent. of other impurities, and this is the grade desired for water works. Limes containing more than 3 or 4 per cent. of magnesium oxide should be avoided if possible. Some cities pay a bonus for absence of magnesia, and penalize for more than a given per cent. of this objectionable material. No core or unburned lime should be present.

Slaking

When quick lime is treated with water, heat is given off and the lime is reduced to paste or mud of lime. If core is present, lumps of it will be found unslaked. Not more than four pounds of water should be added to one of lime to slake it. If convenient, hot water gives better and quicker results than very cold water. In fact, very cold water should be used very carefully in slaking lime. If too much be used at one time, the lime will not slake properly. On the contrary, care must also be used in slaking lime with warm water, lest the lime get too hot and burn. When it gets too hot, more water should be added and the lime stirred with a mortarman's hoe. In case mechanical stirring devices are provided, the lime can be stirred mechanically and this is much better than using manual labor. Any soft, mushy lumps must be broken up to allow the water to get to the center of them. When the lime has ceased to bubble and absorb water, it has passed the danger stage and may be left till required. It will continue to undergo more perfect slaking if left to lie as a thick mud for a number of hours.

Hydrated Lime

When it has been slaked it has then become a hydrated lime, and is in much the same condition that a dry hydrated lime would be if mixed into a thick mud with warm water. There is this exception: a quick lime slaked as above does not wholly lose its granular character. Some of the grains still retain the same granular state as the original stone or the grain of the quick lime. If these particles could be well ground up in water, more satisfactory use could be made of the lime and a more efficient one as well. These granular particles do not readily go into solution and more or less of the lime is lost when it is put into the water. This renders an equal weight of lime, slaked as above, less efficient than the same weight slaked and sold as hydrated lime. If both the quick lime and hydrated lime be chemically pure, 56 pounds of the former will be equal in strength to 74 pounds of the latter. In other words, 74 pounds of hydrated lime contain 56 pounds of quick lime and 18 pounds of water. Hydrated lime of commerce commands a larger price by the pound than does the quick lime. It is, however, much less susceptible to deterioration and is easier to handle in storage. Quick lime rapidly undergoes air slaking in moist weather, and is difficult to keep for even a reasonable period of time without being subject to large deterioration. It is almost as expensive under all the conditions obtaining as the hydrated lime.

Solubility

In using lime we are handicapped somewhat by the low degree of solubility. Most chemicals are more soluble in hot than in cold water, but lime forms an exception to this rule.

In water of ordinary temperature we can dissolve only about sixty grains of lime in one gallon of water. The ratio of solution thus becomes 60 to 58,411 or 1 to 9735. For this reason we are compelled to resort to devices capable of manufacturing large volumes of lime water or else use this material in suspension in lime water and this latter procedure is the one most generally followed in handling this material.

This involves difficulties in maintaining the lime in suspension. In order to obtain the knowledge of how much lime to use to a tank, we resort to the method described on pages 42–43, but instead of preparing a charge to last twenty-four hours, it is the usual practice to arrange the charge so as to last only about eight hours, unless the lime tanks be larger than are ordinarily provided.

The charge, after being weighed out, is added to the lime tank and water run in until the tank is full. By this time practically all of the mud has dropped out of suspension, and only the clear supernatant lime water shows above.

This, as previously stated, contains only about sixty grains per gallon of calcium oxide in the form of calcium hydrate in solution. Sixty grains of calcium oxide are equal to 79.28 grains of calcium hydrate.

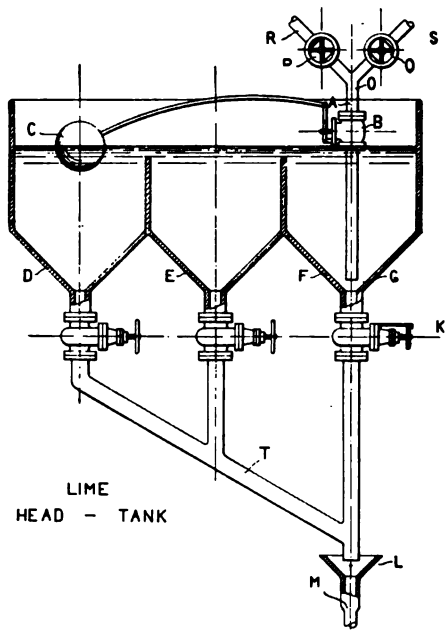
Suspension

The heavy lime mud in the bottom of the tank must be made to remain in a state of homogeneous suspension if we are to use it as desired, and for this reason some form of mechanical agitation must be employed from the time the tank goes into use until it is exhausted. Each lime tank must be equipped with this form of mechanical agitation.

Metals Affected

Lime will quickly attack lead and dissolve it. Brass offers a better resistance, but is rather quickly destroyed, so it is not advisable to use any lead or brass in considering devices where they will come in contact with the lime solution. Wood offers an excellent resistance, and cast iron a still better one to the action of this reagent, and therefore these two materials afford us the best possibilities for construction of the stirring devices. Some engineers have used wooden propeller blades covering nearly the entire area of the tank bottom in their sweep and placed within two or three inches of the bottom. These are driven by power at a very slow speed, not over ten revolutions per minute. This type of design is not the best. To date, the device shown in the plan and elevation, page 18, has proven the most satisfactory. It is driven at high speed by any desirable type of motor at not less than 450 nor more than 750 revolutions per minute.

It is important that the motor speed shall be kept within these speeds. A speed slower than 450



Fargo Laboratory

R. P. M. will not produce satisfactory results.

Circulation

The circulation of liquid is shown by the arrows. The flow up the sides and down the center is so swift as to maintain a perfectly homogeneous suspension from the time we begin to draw from the tank until the level reaches the top of the cylinder casing around the propeller blade, when the tank is put out of service and another one put in.

The pipe line connecting the lime tank to the head box should be plain black iron or steel pipe. It should be of ample size to accommodate the largest flow ever required and it *must not be trapped.* It should have a good drop throughout its entire length so no mud of lime will collect at any point in its length.

Lime Head Tank

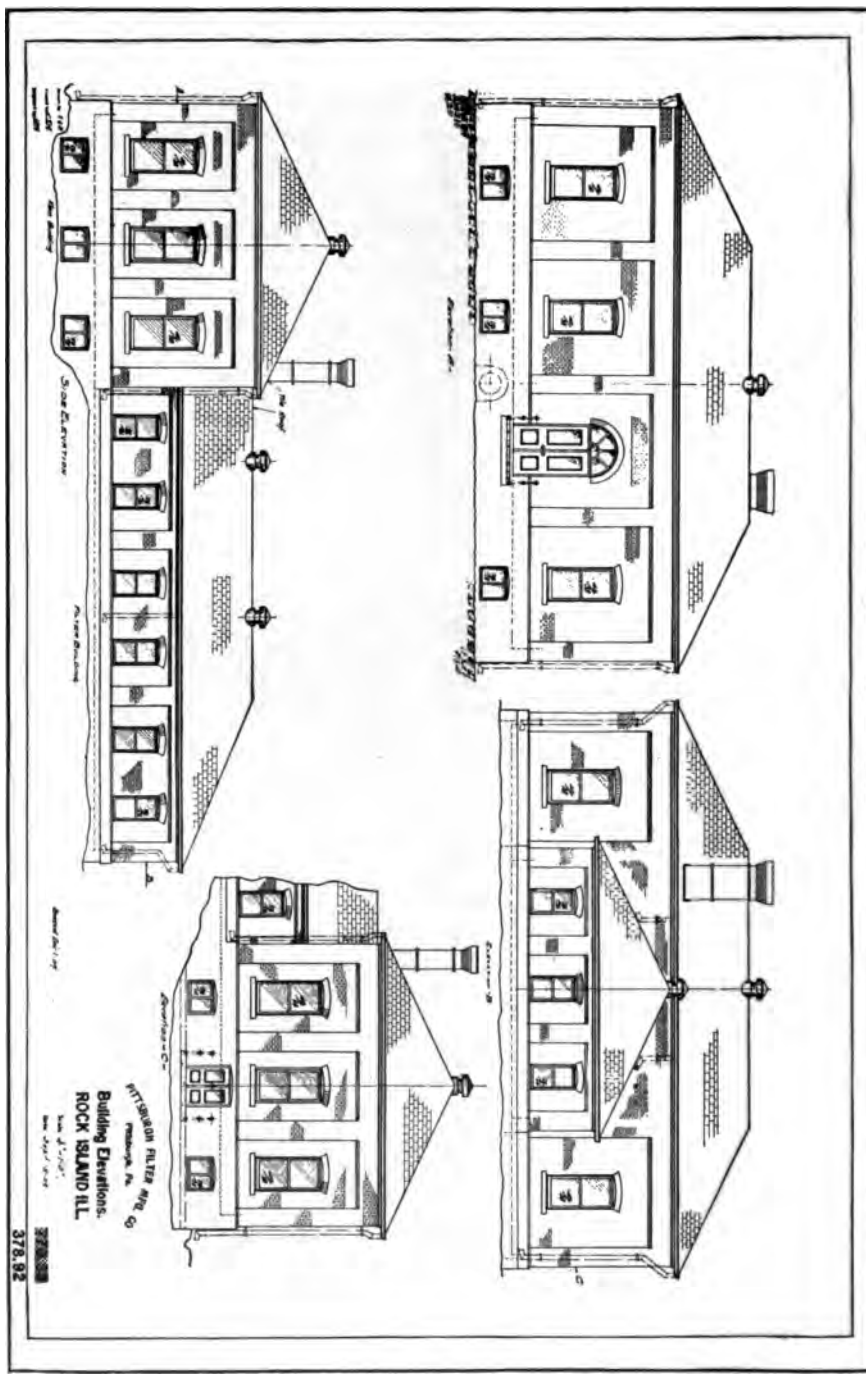
The head box should differ from those in general use and should offer no chance for the heavy materials to find a resting place therein. The sketch, page 50, shows a fairly good arrangement for a fixed rate flow.

The discharge lines R and S from the two lime tanks are equipped with valves P, Q, which are placed as close to the lime tanks as possible. These lines unite at O and form A, on which a throttling valve B is placed. A float C maintains a constant level shown as a dotted line above K, the chemical orifice. If level falls, B is partially opened; if it rises, B is partially closed, thus maintaining a practically constant level. No lime mud can lie in the bottom of F, as the flowing liquid carries it to G and thence to K and into the funnel L. The line M carries it on to the point of application. Some overflow from F occurs into E, but this is out of the main flow which follows the general directions of the arrows and therefore this flow from F carries little suspended matter, being almost clear lime water. That which is carried over, however, falls mostly to the bottom of E or D, thus keeping a clear lime water in D in which the float C can rest without being interfered with by lime mud collecting under it. Any mud which does collect in D, E or F can be turned off into the manifold T and discharged into M, which should have a good and practically uniform drop from the funnel to the point where the lime enters the water.

An arrangement of this kind allows the application of a milk of lime with no practical difficulties and with sufficient accuracy to meet the practical requirements for a fixed rate device.

Mixing Chamber

After both chemicals have been applied to the water and particularly at and after the point where the lime has been introduced, the water should not be allowed to rest or assume a slow flow until all of the available lime has gone into solution. In other words, the water


Building Elevations.
ROCK ISLAND ILL.
378.92

should be compelled to maintain a velocity of flow sufficient to carry the lime with it until the former has gone into solution. From this point on the velocity of flow may be decreased slightly, but it should still have sufficient velocity to form and carry the coagulum. Up to very recent times this essential of mechanical filtration has not been sufficiently emphasized by designing engineers. The necessity for a mixing chamber to perform this very important part of the work is now generally recognized by the foremost exponents of the art, and most of the plants recently devised show this advance. Some of the older plants are installing mixing chambers and are thus demonstrating their value.

Types

There are two types of mixing chambers in use. The plant at New Orleans is equipped with one type, Columbus has a modification of the other, but Fargo forms a far better illustration of the second type of mixing chamber.

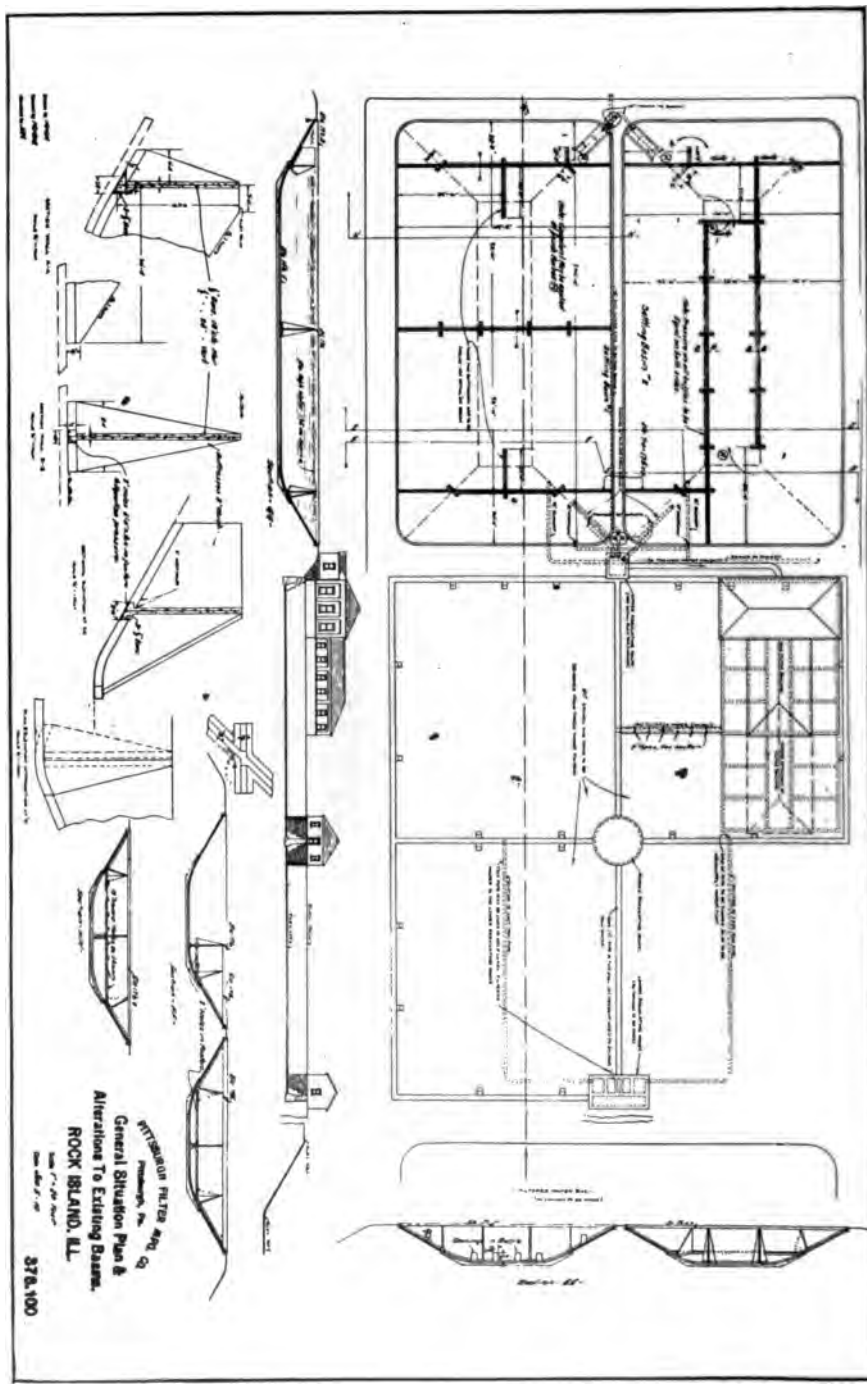
In the New Orleans type the water makes a long horizontal flow at rather high velocity, then descends and travels back under the first apartment, crosses over and goes back at the same level, then rises and returns at the higher level. A series of these apartments compels the water to travel through the maze for about one hour before it is permitted to enter the settling reservoir.

The objections to this type may be summarized as follows: It costs more to build, it costs more to house in and keep from freezing, it requires more land and is less flexible and more difficult to alter to meet changing conditions of purification demands. The velocities of flow through the upper passages vary rather more than is desirable over those in the lower passages. There is a tendency to form larger deposits of sludge in the lower passages than is desirable and on accelerated velocities these deposits are lifted and carried on less completely than in the up and down type.

At Fargo the water flows down and then up, over and under baffles of wooden construction, the long flow being vertical instead of horizontal as at New Orleans. The Fargo type takes less ground, enables the chamber to be housed, and in general is the preferable construction, particularly for cold climates. Both types consume some head and this must be allowed for in design. The velocity of flow required to form the coagulation should be not less than .5 foot per second. The maximum velocity should not exceed 3 or 3½ feet per second or too much head will be absorbed.

Capacity

The size of a mixing chamber should be such as to insure at least one hour's travel through it at rated capacity of the plant. The coagulum caused by some chem-


General Situation Plan &
Alterations To Existing Bases.
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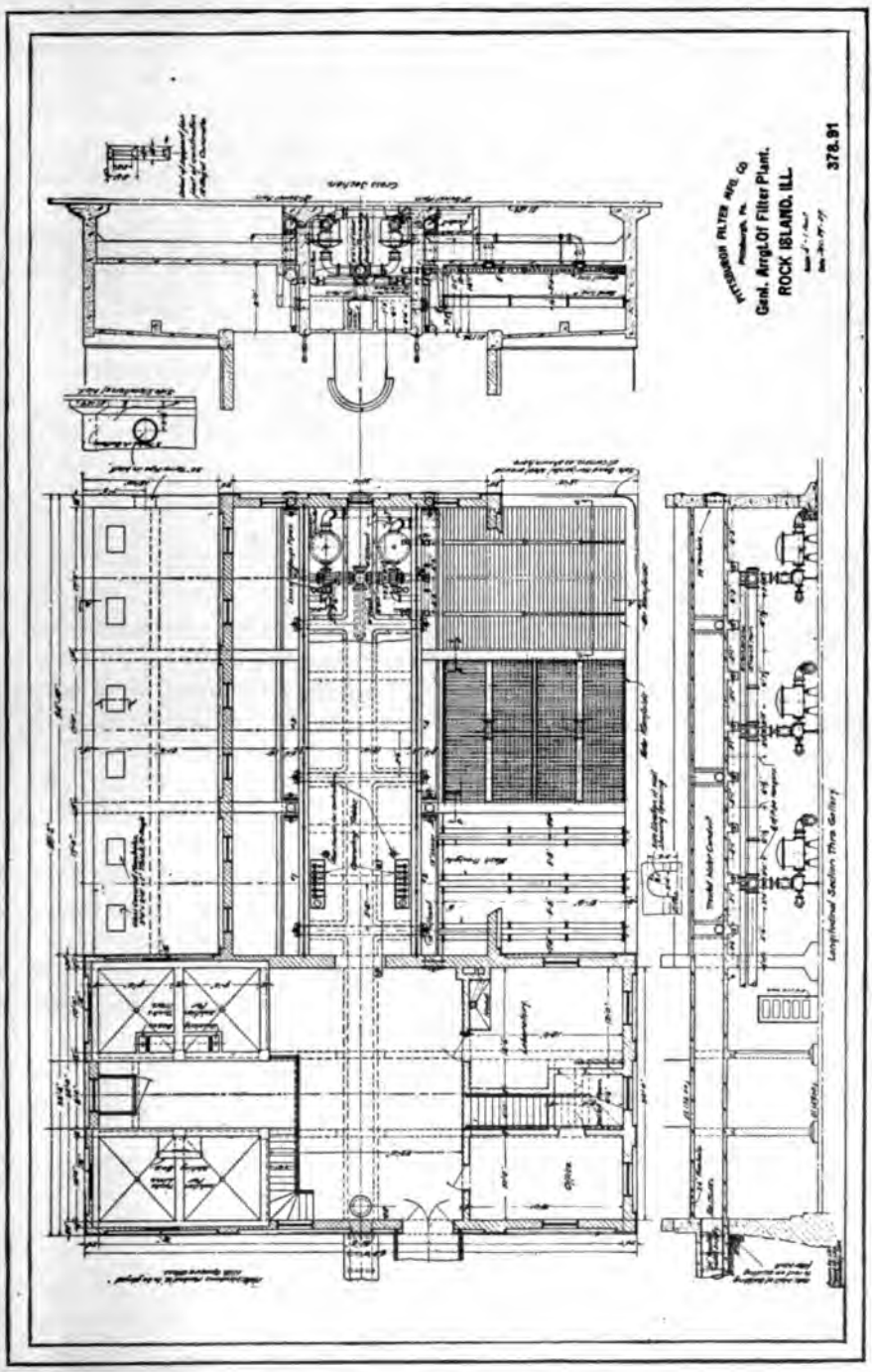

PITTSBURGH FILTER MFG. CO.
Gen'l. Arr'g.Of Filter Plant.
ROCK ISLAND, ILL.
378.91

icals is rather slow in forming, requiring twenty minutes in very cold water, and this should be borne in mind. Such slow reactions are materially hastened and helped by the action of the mixing chamber, but provision should be made to give ample time for these slow-acting chemicals to form their coagulation, even in the coldest water.

Forming Coagulation

Forming a coagulation means to cause it to gather in large feathery flocks. Coagulation first forms in very fine, perhaps submicroscopic flocks; at least, the eye cannot see the individual flock. Later, these flocks become large enough to be seen as separate and distinct by a very keen eye, but still remain quite small and not sharply differentiated from the water in which they float. The action of the mixing chamber causes them to grow in size by gathering several or many smaller into one larger flock, and they may continue to accrete until they are very large comparatively, and in this condition the water, between the flocks, appears clear and brilliant, even sparkling, and the flock is sharply differentiated from the water in which it is suspended. One simple method of testing for a proper coagulation is to take a glass of water to a bright light and hold the fingers well separated on the side of the glass away from the eye. If the coagulation is in a perfect state, the outline of the fingers and even the markings thereon may be clearly and sharply seen, and the water appears to sparkle between the flocks. Where the outline is blurred or the markings indistinct, or the water does not appear brilliant and clear, the coagulation is not so good.

When the coagulation reaches this stage of formation, it is in the very best possible condition. In a properly designed mixing chamber this will occur before the water reaches the end of the chamber. In this state the coagulation is ready to fall out of suspension the moment opportunity is afforded or the flow becomes slow enough to permit.

The water should leave the mixing chamber through an opening of such size as to not materially increase the speed or velocity above that obtaining when passing through the chamber. On entering the settling basins, the velocity is quickly decreased, owing to the increased cross section of flow, and the coagulated matter rapidly settles out. Because of this, the efficiency of a settling basin is largely augmented by the action of the mixing chamber and more efficient results from sedimentation can be secured. Just how much better these results are than where no mixing chamber is employed, it is difficult to estimate, but it is certain that a smaller settling basin with mixing chamber will give better results than a larger one without the mixing chamber.

Water must not enter settling basins at or near bottom, but at or near the top of the same.

Settling Basins

Baltimore, Md.

Courtesy of
J. W. Armstrong, Engineer

Pumping Station

View Across Settling Basins

Baltimore, Md.

View Across Settling Basins

In addition with a mixing chamber, it is possible to use a much smaller amount of chemical treatment and get practically as good results from sedimentation and filtration as though a larger quantity were to be employed without such a chamber. The plant at Fargo, North Dakota, has shown some results which have never previously been obtained, and these are apparently traceable to the splendid action of the mixing chamber.

After leaving the mixing chamber, the water passes to the settling basins.

The Settling Basins

A great deal of the success of any plant will depend on the settling basins, their arrangement and efficiency of operation. Many plants have failed more or less materially to fulfill their function because of errors or lack of attention to this very important part of the plant.

The function of the settling basins is to cause the larger portion of the suspended matter to fall out of and be removed from the water in which it is suspended. The more completely this is accomplished the greater the efficiency of the settling basins. While this holds true it is possible to remove too much of the suspended matter unless the filters differ from those in general use or unless secondary chemical treatment can be given the water going on the filters.

Suspended Matter

The suspended matter consists not only of that originally present in the natural water but also that artificially created by chemical treatment as well as a major portion of the bacterial content of the natural water, which is caught and enmeshed by the action of the coagulant.

A mixing chamber which functions properly will produce or create a type of suspended matter which is in the best possible condition to be removed by the action of the settling basins and if these perform their function properly the larger part of the suspended matter will be removed in passing through the settling basins. Some of these basins have shown efficiencies as high as 95 per cent. in removing suspended matter and bacterial content and where such efficiencies can be maintained the filters are relieved of the larger portion of the work which they would otherwise have to perform and they are only called upon to put what some operators call the final "polish" on the water.

Wash Water

Where the filters are only called upon to do this they can be made to operate for longer periods of time between washings than where the efficiency of the settling basins is lower. This means a considerable saving in wash water and expense of purification. It is much cheaper to wash a ton of mud out of a properly designed settling

basin than it is to wash an equal quantity out of a filter. Unfortunately this is too often lost sight of even if it be known. In most of the medium sized plants the cost of wash water seldom falls below $0.375 per 1,000 cubic feet and if one per cent. of wash water can be saved, the saving per one million gallons filtered on this basis amounts to $0.50. Thus a plant averaging ten million gallons per day, saving one per cent. of wash water, is really saving $1,825.00 per annum or sufficient to pay the interest on an investment of $45,625.00 at four per cent. interest.

Successful Settling Basins

Nearly, if not all the basins which have shown high efficiencies have been of rather shallow design. Deeper types have not usually shown as satisfactory results. It is apparently better to have the water enter the settling basins at or near the surface rather than at a lower depth. Attempts have been made to distribute the water entering the basins over the whole cross section of the basin and thus to secure an equal velocity of flow through the basins at all depths in the cross section of the basin, but these attempts have not been very successful in accomplishment, and even where a partial success has been attained the results do not seem to indicate that this is desirable practice.

On the contrary, the introduction of the water into the basin over a weir extending almost or entirely across the end of the basin and located at or near the surface has apparently produced much better results. The forward movement of the water in a straight line should not, apparently, persist for too great a distance. If deflected within three or four lengths of its width the results seem to be improved. After the suspended matter has fallen below a certain horizontal plane it is not good practice to permit it to rise above this plane at any further progress in its travel. A skimming weir at the outlet of the last settling basin should collect the water into a skimming chamber from which it should pass to the filters.

Waterways

The waterways between the settling basins and filters should be large and free from sharp bends in order to prevent breaking up the remaining coagulation.. If the waterways are small or the water is suddenly caused to change its direction of flow, the remaining coagulation will be badly broken up, and having no chance to reform, the filter is compelled to handle a finer flock than is desirable, and lowering of efficiency inevitably results.

These are some of the things which observation of a large number of settling basins of various types and sizes seem to justify. It must be admitted that there is a great deal more involved in the proper design of a settling basin

View from Rear

Baltimore, Md.

View from Rear

than is yet known. A more careful study of the problem might lead to considerable improvement of this feature of the plant. A judicious amount of experimental work along this line might give remarkable returns and enable a much better and more intelligent design to be eventfully arrived at. The practice of designing any shape or size of settling basin as seems best adapted to the site should be discouraged and more thought given to this feature.

Observation

Operators should carefully observe the action of the settling basins. Much can be learned in this way which will enable the operator to secure better results under some conditions than if he does not know what any given set of conditions is liable to produce in results. Too little attention is usually paid to the sludge zone and its effects upon the action of the settling basins. A careful study of the sludge may be very useful to the operator. If the sludge is allowed to accumulate for too long a period of time it may affect the results of purification very materially. If removed too frequently a loss of treated water and wash water occurs and a larger expense than necessary incurred.

Testing

A rod, which is long enough to reach the bottom of the settling basins conveniently, can be made into a sludge zone tester. To do this a number of wide or salt mouth bottles of about four ounces capacity should be affixed to the rod with their mouths looking upward. These should be spaced at equal intervals apart, say six or eight inches apart. A rod of this kind, if carefully and slowly lowered into the settling basin until the bottom is reached and then carefully and slowly withdrawn will show the depth of sludge and the approximate density of the same at various depths.

A study of the sludge zone, carefully conducted, and checked against bacterial tests of the efficiencies of the basins, will, in time, give the operator a line on the action of the basins which may be quite useful. Every settling basin will show certain peculiarities in the formation of the sludge zone, the quantity of sludge which can be permitted to accumulate without detriment to the bacterial results or economical washing of the filters and in various other ways the information obtained by watching the settling basins may be made useful in the operation of the plant.

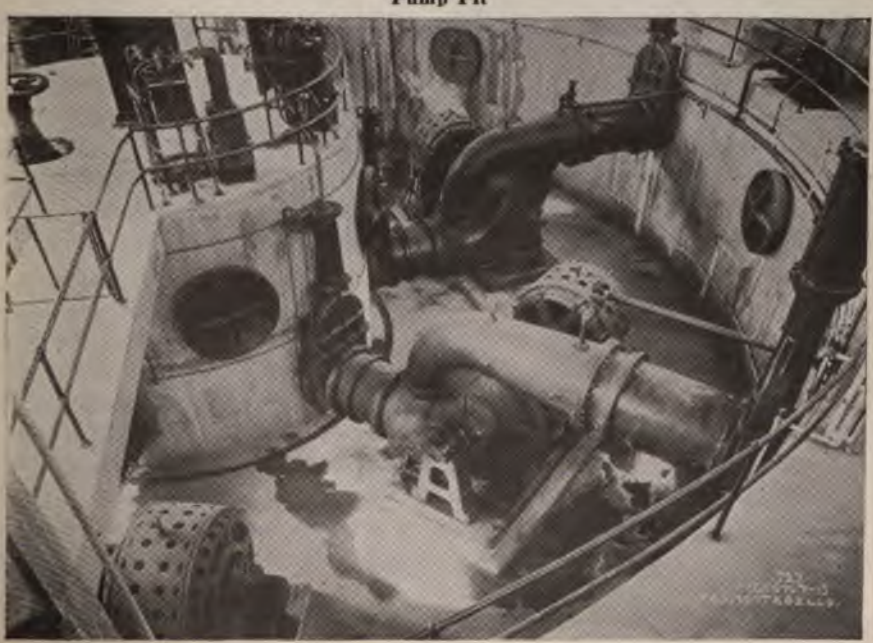
Filters

The filters form the most interesting part of the plant. It is here also that the greatest skill of the engineer and contractor finds opportunity for display. Upon the ability of both depends the success or partial failure of the plant as a whole. Unless the filters perform their part, the plant must always

Filter Building

Baltimore, Md.

Pump Pit



be considered a partial or complete failure. It makes little difference how perfectly the rest of the plant is designed or built or operated, if the filters fail to perform their function the plant cannot be deemed wholly successful.

Some engineers give considerable attention, as far as their knowledge permits, to this part of the design, but it is here particularly that the knowledge obtained from practical operation should be manifest. Unfortunately, both design and construction too often show a lack of this. Some engineers pay absolutely no attention to this phase of the subject, seeming to think that any size or shape of tank, however equipped, can be made to perform all the functions of a properly designed filter. This, however, is very far from the truth, and the sooner it is realized the better it will be. In no other part of the design or construction is greater skill or knowledge required.

While noticeable advancement in the extent and efficiency of filter equipment has been made in recent years, it is equally noticeable that little advancement has been made in the filter itself. In fact, it is doubtful if some of the modern examples of the art compare in some respects with those of earlier construction. With all due consideration for the engineering talent employed, it is questionable if the present-day design equals that of the past when the design was carefully worked out in and from the light of actual operating knowledge by operating engineers. The results obtained in the nineties with the old standard type of Jewel filter, equipped with mechanical agitators, have never been duplicated in some respects by the more modern and at least equally costly designs.

Cleaning

More trouble is experienced today with the filter beds and the cleansing of the same than ever occurred with those of the older design. While some advancement is manifest in this direction, many modern plants have much more trouble in this respect than is generally known and much greater difficulty than was ever experienced with the older types with mechanical agitators. The air wash employed in place of mechanical agitation seems only to accentuate the trouble at some plants under some conditions, and while part of the trouble at these plants may be attributable to imperfect results from chemical treatment, mixing and sedimentation, it is inconceivable that all the difficulty is caused by these faults.

Experimental

Thus our modern filter still offers some problems which have not yet been completely solved, and the real occasion for comment on this condition is that so little attempt is being made on the part of engineers to solve them. While design and construction have changed and are changing, it is rather remarkable that no practical experimental

work is being carried on by anyone at the present time to ascertain how troubles arise or how they can be corrected. The experimental plant played a very important part in the early days of the art, and must again if we are to make further progress in design and construction. A few dollars spent experimentally may save hundreds or thousands in design, construction and operation, and in addition, result in producing vastly better and more satisfactory purification.

Breaking Coagulation

One of the difficulties already referred to is that of conducting the water from the settling basins to the filters without breaking up the coagulation. Large waterways without bends or sudden interruptions in the direction of flow materially assist in this particular. If the velocity of flow from the basins to the filters remains low, there is not so great an opportunity to break up the remaining coagulation. If the direction of flow is not interfered with by causing the water to violently change its direction, there will be a reduced tendency to break up the coagulation. If the coagulation or flock is broken up, the filter will certainly have less chance of successfully performing its function.

Another source of trouble lies in the difference between the relative difference of sizes of sand beds, rated capacities, and amount of suspended matter in the water from the settling basins as exemplified in the modern plant and that of fifteen years ago.

Other things being equal, the conditions which produced efficient results fifteen years ago should do so now, but if one condition or one set of conditions be changed, it follows that further changes should take place if the same results are to be attained.

Changing Conditions

In some of the old plants which produced really wonderful results, the amount of suspended matter in the water from the settling basins ran up to one thousand or even two thousand parts per million. The effective size of the sand was as coarse as .37 m.m., the rate of filtration as low as ninety million gallons per acre of sand per day at rated capacity, while the length of run between washings was as short as three or four hours. The bacterial results in some of these plants averaged as high as 98 per cent. or better and were secured without the use of sterilizing reagents.

Under present conditions, the amount of suspended matter and the size of the flock has greatly decreased. In some plants the water leaving the settling basins does not carry over six to eight parts per million of suspended matter. This reduction in quantity and also in size is due to the larger size and more efficient action of the settling basins.

The normal rate of filtration has increased until it is now about 125

million gallons per acre of sand per diem. The length of run between washings has increased until some plants have had runs of over four hundred hours between washings; while the effective size of the sand has not been changed sufficiently to compensate for these other changes.

A decrease in the effective size of the sand would have a tendency to decrease the length of run, and enable the filter to handle the smaller size and volume of coagulation and more nearly restore the balance between present and past conditions of work. To state the thing differently, a finer sand bed with the upper layer of sand of from four to six inches having an effective size of .20 m.m. or thereabouts, would probably render the results from some plants more satisfactory.

Wash Troughs

The water entering the filters usually does so by means of the wash trough. These troughs are of various shapes and sizes in different plants. They are usually of peculiar form, depending on the engineer designing the plant. The main function of these troughs is to carry off the wash water. They should be of ample size to do this and still have some capacity to spare. The top edges should be as nearly absolutely level and in the same horizontal plane as is practical. They should be as shallow as practical and the top edges as close to the sand as possible. They should be spaced not more than six feet apart on centers so that the travel of the wash water will be short and its removal promptly effected. They should be provided with sand catchers or deflectors so the wash water, while carrying the largest possible amount of suspended matter, will not carry sand away. When the filter is in service, the sand should clear the bottom of the troughs by at least one inch. If the bottom of the trough is immersed in the sand, that much of the sand bed becomes ineffective and of no value. When washing, the bottom of the troughs should be immersed in the lifted sand bed to at least four inches. They should be tight and free from cracks or crevices throughout their length. They should discharge their wash water freely and never flow quite full under full wash load. Any trough meeting these requirements will prove entirely satisfactory.

Sand Bed

The sand bed consists of from two to three feet of sand and from twelve to six inches of gravel. The gravel is usually graded from fine to coarse and the sand should be.

In some of the filters employing sand and gravel as a filter bed, considerable difficulty is experienced in maintaining the gravel at the bottom and the sand on top. The strainer system for water is usually placed below the coarsest gravel, on top of which the finer gravel is laid in graded layers, and on the gravel the sand. In cases where air is used in washing, the air manifold

Pump Station and Aerator

Mixing Chamber Gallery

Baltimore, Md.

Chemical and Head House

Chemical Preparation Room

is ordinarily placed on top of the gravel and below the sand. In some of the larger plants a bronze screen of wire mesh is placed on top of the gravel and anchored in place. The purpose is to hold the gravel down.

The life of this bronze mesh is rather brief in some plants and the cost of renewal high. Unless properly anchored, it is liable to be lifted or torn from its anchorage, necessitating rather costly repairs. When properly placed, this solves the question of holding the gravel on the bottom of the filter bed.

Air Wash Troubles

Where the gravel is not tied down and particularly where air is used for washing, trouble has been experienced at many points by a bed inversion in spots. When this occurs, the gravel is partially or wholly lifted from the bottom in spots and the sand takes its place, or the sand and gravel are mixed and a "hard spot" forms which does not wash effectively, and imperfect filtration results. In some plants the operators have to be continually on the lookout for the formation of these "hard spots," and their elimination is both troublesome and costly.

A considerable amount of experience led us several years ago to advise that these difficulties could be overcome by making the gravel layer thicker and coarser, heavy gravel being employed for the bottom layer. Experience has confirmed this. A gravel layer eighteen inches thick, with the bottom layer composed of pieces two inches in diameter and graded to 1-16 inch at the top, will not be lifted or the bed inverted at any practical rate of washing, if air is not used in washing. The results are apparently as good or better than where the gravel is tied down with bronze screen and the wash is more even and economical even when air is used. As far as results are obtainable, this type of construction appears to be somewhat better than those formerly employed.

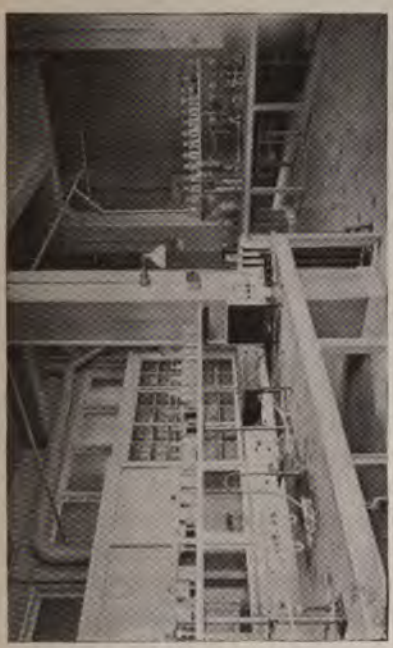
Strainers

The strainers, used at the bottom of the filter bed, have been the subject of much thought and effort on the part of filter builders. They are used to carry off the filtered water; to hold back the sand and gravel and to apply the wash water. Many forms have been patented and much money and effort expended to devise a satisfactory type. The last word has evidently not yet been written on this feature.

Where the gravel is coarse and heavy and remains in place, and does not allow the sand to reach the bottom, it probably makes little difference what type of strainer is employed as long as the manifold is properly designed and the capacity of the strainer approximately correct, except in so far as the expense and durability are concerned.

Manifolds

The proper design of the manifold is one of the essentials to a



Chemical Laboratory

Chemical Controllers

Baltimore, Md.

Filter Gallery

Inlet Gallery

free and perfect washing filter. The requisite is that each square foot of the filter bottom shall always have the same volume and pressure of wash water applied to it that every other square foot has. In order to do this the cross sectional area of the manifold usually decreases as its length increases. Where the filter bottom is large, as in the case of a four-million-gallon unit, the filter bed is generally divided into sections and each section is supplied by a branch of the main manifold, and these in turn reduce as the length increases.

The object is to maintain an equal velocity of flow in the manifold through any and all cross sections of the same, both when washing and when filtering. This can only be approximated in practice, but the best results are attained the nearer the attainment is to the ideal.

Filter Controllers

In the old style filters no effluent controllers were employed. The plant at Lorain, built in 1896–97, had none, and some plants built recently have not been provided with these devices. If the operator possesses sufficient skill and uses care in handling the valves, equally as good bacterial results may be obtained without controllers as have been obtained with the ordinary old style fixed rate controllers. In the hands of unskilled and careless operators the hand regulated filter is liable to give very erratic results, and in these cases the fixed rate type first introduced tends to render the results less erratic.

Constant Rate Controllers

The object of this type of controller was to maintain a constant and uniform rate of flow through the filter to the clear well or high service pumps. When a filter had just been washed and thrown into service it tended to pass too much water. If the effluent valve was fully opened at such a time and left open, the rate of filtration was excessive, in some cases as high as 250 million gallons of water per acre per diem. Under such conditions, the sand bed rapidly clogged and the rate decreased proportionally, although excellent bacterial results could be obtained if the coagulation was adapted for the rate. This was fully proven by the Louisville experiments previously referred to. The length of run was usually very short and the percentage of wash water very high. By only partially opening the effluent valve at the beginning of the run and gradually opening it at long time intervals at the start and at shorter intervals as the length of run increased, the time period between washings was increased, and while the rate of filtration never rose as high, the amount of water passed between washings was increased and the percentage of wash water decreased.

This caused the introduction of the fixed rate type of controller. When a filter is clean and has an available loss of head of twelve feet,

if the entire available head is employed at the commencement of the run, the rate of filtration thus established can never be increased, but will decrease very gradually at first, but much more rapidly as the length of the run increases. If part of this head be held back the rate at the start will be lower. As the friction in the bed increases, due to a gradually accumulating load of coagulant and impurities caught and retained by the sand, more and more of the reserve head can be brought into play to overcome the bed resistance until the entire available twelve-foot head shall have been utilized and the rate can be maintained constant and uniform up to this time.

The controller sought to accomplish this function by throttling the effluent at the start and gradually opening the throttle as the head was consumed and the friction increased, thus establishing a fixed rate of discharge from the filter. Those first introduced sought to accomplish this by utilizing the flow from the filter to actuate the throttling device automatically and govern the flow in this manner. These devices are still made and sold, but their use is becoming less common and they will probably continue to lose popularity until entirely replaced by the newer and more satisfactory type. The reason for this lies in the difficulty of designing and manufacturing a controller of this type which will give a good control. The power available from the flow from the filter is not sufficient to overcome a sticking throttle and it is practically impossible to devise a throttle which will always act as a throttle and never stick, or which will always move as required under very slight increases or decreases of head.

Overrunning

If it does not do so, the power has to accumulate until it becomes sufficient to overcome the resistance, and when this happens the throttle moves abruptly and consequently overruns, and this sudden opening or closing of the throttle causes an hydraulic blow to be delivered to the filter bed, and may cause the filter to break, either partially or wholly.

Breaking Beds

In other words, it causes the layer of mineral matter on the bed to be disturbed either to a very slight extent which may not be easily detected, or to such an extent as to cause the water passing the filter to become noticeably turbid. In such cases the bacterial results are adversely affected. In case of a bad break the bacterial efficiency may be almost wholly or even completely destroyed. An operator can manipulate a controller of this type so as to cause a filter to break very badly, and where this can be done by manipulation, it may reasonably be expected to occur accidentally, due to sand particles passing the strainer system and lodging in the working parts of the controller, thus causing it to stick

and to refuse to move on slight changes of pressure.

Newer Type

The newer type overcomes this difficulty by introducing an outside power capable of operating the throttling device, irrespective of the opposition offered by sand particles or other similar influences, and if this power is properly applied such a controller becomes a very useful and satisfactory device.

While a fixed rate controller of this type fulfills the desires of some engineers, it fails entirely to satisfy the demands of others. In the early days of the work, it was assumed that the fixed rate controller was the best solution of control, and because this idea was the one earliest advanced and most widely advertised, it has become a matter of course, and many do not really think there can be anything different and still satisfactory.

Variable Rate Controllers

However fixed this idea may have become, it is not possible to dispute the fact that a fixed rate type of controller fails in some respects to meet conditions as they exist in the average filter plant. The reason for this is that few plants, if any, have fixed rate conditions. Consumption varies, and usually this variation is relatively large during different hours of the day and night. In such a plant the volume of water discharged from the filters must vary accordingly or else the plant must be equipped with a clear well which is sufficiently large to take care of these variations in demand. Very few filter plants are provided with clear wells of this size, and therefore conditions necessitate changing the rate of filtration in all filters to meet the demand, or the cutting in and cutting out of filters, as occasion may require, in order to maintain the necessary storage of filtered water. Where the filters are cut in and out of service to meet the consumption demand, some of the filters are out of service nearly all the time and others part of the time. Some years ago some engineers began to see this was poor practice. Allowing a filter to remain out of service for a day or week does it no good and is liable to do it a great deal of harm. Bed growths may start and become very annoying. It is not good business to allow a large and costly equipment to lie idle and unproductive, if it can be avoided. Lying idle in this case means more rapid deterioration than would occur in continuous use.

Economy

The most important objection to this method of operation is found in the fact that it is cheaper to operate a plant at low speed than at high, and better results from every viewpoint can be obtained at a low rate than at a higher.

It is essential, however, that the demand for water shall always be promptly and completely met, and therefore means must be provided to meet any demand within the

capacity of the plant. The real problem is, therefore, how to provide a type of controller which will adjust itself to the consumption demand and control the rate of filtration below any given maximum down to zero in synchronism with the high service pumping rate, and to do so without the possibility of breaking filter beds. It is essential that the maximum rate at which the filters can be made to operate shall never exceed a predetermined rate, and this rate should never exceed the limit of safety, and it is also desirable that this type of controller shall be capable of being set at any fixed rate from zero to the maximum without much effort or expenditure of time on the part of the operator.

Earl Variable Rate Controller

This problem was finally solved by the General Superintendent of the Sewerage & Water Board, New Orleans, La., and is known as the Earl Variable and Fixed Rate Controller. The maximum rate was fixed at 175,000,000 gallons per acre per diem for the New Orleans plant, and this has proven very satisfactory for their conditions and plant.

In this device, the height of water in the clear well controls the filters. As the clear well rises above a given level, all the filters are automatically and equally reduced in rate of filtration, and as the level falls below a given point all the filters are automatically and equally increased in rate of filtration. With such an equipment all the filters can be maintained in operation all the time. The level of water in the clear well can be held within any two predetermined or desired levels, one minimum, below which the clear well level will not fall, and one maximum, above which the level will not rise, and these two points can be established at will within any limit which may be called for. In other words, the tendency of the device is to maintain a constant level, which in turn means a constant reserve supply of water in the clear well, irrespective of the amount taken from the clear well by the high service or wash pumps within the limits of the filtration capacity of the plant.

Advantages

The most important and beneficial result is that of being able to maintain all the filters in service at all times at equal rates of filtration and at a rate which is only high enough to maintain the supply of filtered water. Any sudden increase in the service consumption, such as would be caused by a large fire or a break in the high service distribution system, does not suddenly affect the rate of filtration, as the clear well acts to prevent sudden changes of rate.

Another very desirable feature of this type of filter controller is the additional available overload capacity which may automatically be called for at any time.

With older types the operator is compelled to take some time

and labor if the rate of filtration is increased beyond the normal 125,000,000-gallon rate. In some types this rate cannot be exceeded and in others only with considerable labor and time.

With the Earl type the controllers automatically respond to any demand by the high service pumps up to an overload capacity of 40 per cent., which is as high a rate as should ever be used.

As the high service pumps drop the load, the controllers automatically reduce the rate accordingly, and this feature practically means about 40 per cent. additional filter capacity for emergency use and is therefore of real value.

The device is simple and positive in operation and not easily put out of order. In fact, it has proven remarkably reliable and fool-proof, and of value both at New Orleans and other points where it has been installed.

Meter Controller

The older type of Earl Controller seems likely to be supplanted by the newer type of Earl Meter Controller. This later developement has all the desirable features of the earlier design and in addition the flow of the water from the filter is indicated by an indicating device, recorded on a chart by a recording device and integrated by a counter similar to an ordinary water meter clock counter.

The desirability of doing this has long been apparent to all practical filter operators. Under present practice no one can tell even approximately how much water is passing a filter at any moment or for any period of time.

The operator knows some filters filter more water than others between washings, but no one can tell how much or how little. A device of this kind will enable the operator to gain an accurate knowledge of what each filter is doing every day and the added economy and certainty of results will be increased correspondingly.

This new type will not only enable the operator to gain an intelligent knowledge of what each filter is doing every moment of the day and night, but it will also serve as a check on careless or inefficient operation or waste of wash water.

The difficulty of locating filtration troubles and inefficiencies should be practically eliminated by this device, and its adoption both for the purposes of filter control and chemical control seems very probable.

Wash Water

This unquestionably marks an advance in this particular point of equipment and enables the operator to do some things not previously possible. The saving effected in wash water, due to a larger quantity of water passed between washings, is remarkable and tends to decrease the cost of operation.

The ability to govern the supply of filtered water and maintai[illegible] given level in the clear well en[illegible]

the plant to do just as good and apparently as safe work with a smaller clear well, thus materially reducing the first cost of the plant.

Operation

Assuming the mechanical troubles of the plant to have been overcome and the plant in running order, the first thing the operator desires to know is how to start the purification process. The first step is to determine the amount of iron sulphate and caustic lime to be applied. Before this can be done to best advantage, certain information should be available:

First, turbidity of the raw water.

Second, character of the turbidity.

Third, color of the raw water.

Fourth, amount of free carbonic acid, CO_2, if any.

Fifth, amount of normal or monocarbonate alkalinity, if any.

Sixth, amount of bicarbonate alkalinity.

Seventh, total alkalinity.

Eighth, rate of filtration.

Ninth, effective size of sand.

Tenth, time period required for water to pass through the settling basin.

In order to obtain this data, the operator will have to resort to some simple chemical work to get part of it and to measurements and calculations for the remainder.

(1) Turbidity

One of the simplest and most workable methods for determining turbidity is that given by the United States Geological Survey. While this method may not be as exact as some others, it is accurate enough to serve all practical purposes. The method is given in full herewith as per Circular No. 8, Division of Hydrography, United States Geological Survey:

Division of Hydrography. Circular No. 8
Quality of River Water

Department of the Interior

United States Geological Survey

Measurement of Turbidity and Color

Water in its ideal condition is perfectly clear and limpid, and has a slightly blue color. Filtered water, distilled water, and many spring waters approach closely to the ideal water. Most river waters are, however, either colored by contact with peat, muck, or decaying vegetation, or turbid by reason of mud or silt carried in suspension. Muddy waters are often spoken of as colored waters, and in a sense this is correct where the mud consists of clays or other materials having distinct colors, but for convenience of classification it is better to refer to such waters as turbid waters and to limit the term "colored waters" to those containing in solution vegetable matters which color them.

It has been observed that highly colored waters are usually free from turbidity, and vice versa, this being due to the fact that colored waters usually flow from drainage areas underlain by hard rocks not easily disintegrated, or from regions where

the soils are firm or sandy, and especially from swamps. On such areas there is but little material that would be washed from the river banks and held in suspension, while the coloring material is present in the greatest abundance. In many parts of the United States shales or other soft materials are the underlying beds. These readily disintegrate and form clay soils that are readily washed by hard rains. Waters from such areas are usually turbid and very highly colored.

Turbidity and color are principally important in their effect upon the appearance of water, whereas the impurities discussed in Circular No. 9 have absolutely no effect upon its appearance, and can be found only by their chemical action.

Turbidity

The turbidity of water is a subject of great importance to the sanitary engineer. In questions of water supply, turbidity is often the important feature in the selection of a source of town supply; the number of days upon which the turbidity is above certain fixed standard is also important in that it may determine the size of reservoir required to store clear water sufficient to tide over the time of greatest turbidity, or for the sedimentation of matter suspended in the reservoir water. The importance of this subject varies with the part of the country studied, the waters in the New England States and New York being comparatively clear, while in the Southern Atlantic States and in the Ohio and Mississippi valleys high turbidities are the rule.

In the Northeast the terms "very slight," "distinct," and "decided" have been used by analysts to express the amount of suspended matter present. These degrees of turbidity have been estimated by the appearance of the sample to the eye when viewed toward the light. As the importance of these analyses has been more appreciated, particularly in connection with the purification of waters and the extended studies upon waters of high turbidity, it has been found that a more definite scale was necessary in order that proper comparisons of waters from various sources might be made.

In the filtration of water the engineer desires to know the amount of coagulant necessary to properly clarify the water, and it has been found that the turbidity gives a reliable index of the quantity of coagulant required. The object of the more recent studies has been, therefore, to express turbidity numerically on some scale, referred to some standard, which can be easily reproduced and will be permanent. There has been considerable difference of opinion as to the proper standard for turbidity comparisons, and some confusion has resulted. It is important that any standard selected should be applicable to both field and laboratory practice, and that observations

General View

Akron, O.

Courtesy of
New York Continental
Jewell Filtration Co.

Chemical Preparation Room

Filter Gallery

made by different methods should be readily comparable.

The United States Geological Survey has had occasion, from time to time, to make observations of turbidity of rivers of which discharge measurements were made. Realizing the importance of a uniform standard for turbidity, the Survey has cooperated with Mr. Allen Hazen and Mr. George C. Whipple in order that such a standard might be adopted. Mr. Hazen and Mr. Whipple have made joint investigations and studies, and have recommended the standard given below. This will be used in the future by the Survey, and it is hoped may be generally adopted throughout the United States.

Proposed Turbidity Standard

The standard of turbidity shall be a water which contains 100 parts of silica per million in such a state of fineness that a bright platinum wire 1 millimeter in diameter can just be seen when the center of the wire is 100 millimeters below the surface of the water and the eye of the observer is 1.2 meters above the wire, the observation being made in the middle of the day, in the open air, but not in sunlight, and in a vessel so large that the sides do not shut out the light so as to influence the results. The turbidity of such water shall be 100.

The turbidity of water more turbid than the standard shall be computed as follows: The ratio of the turbidity of the water to 100 shall be as the extended volume is to the original volume, when the water is diluted with a clear water until the mixture is of standard turbidity.

The turbidities of waters lower than the standard shall be computed as follows: The ratio of the turbidity of the water to 100 shall be as the ratio of the original volume of water of standard turbidity is to the extended volume when such water is diluted with clear water until its turbidity is equal to that of the water under examination.

This standard can be used in both field and laboratory. In the field the wire method will be employed as at present, except for a new graduation, while in the laboratory the methods of dilution and comparison now in use for the silica standard will be employed.

Method of Application to the Platinum-Wire Process

A rod with a platinum wire inserted in it at a fixed point and projecting from it at a right angle will be used as at present. The graduation shall be as follows: The graduation mark of 100 shall be placed on the head of the rod at a distance of 100 millimeters from the center of the wire. Other graduations will be made, based on the best obtainable data, in such a way that when a water is diluted the readings will decrease in the same proportion as the percentage of the original water in the mixture. Such a rod, having the graduation shown in the table below, shall be known as the United States Geological Survey turbidity rod of 1902. When this rod is immersed in water the visibility of the projecting platinum wire at the depth from the surface shown in the second column will determine the degree of turbidity, as indicated in the first column.

Graduation of Turbidity Rod of 1902

Turbidity	Depth of Wire Mm.	Corresponding Value on Reciprocal Scale	Turbidity	Depth of Wire Mm.	Corresponding Value on Reciprocal Scale
7	1095	0.023	70	138	0.184
8	971	0.026	75	130	0.196
9	873	0.029	80	122	0.208
10	794	0.032	85	116	0.219
11	729	0.035	90	110	0.230
12	674	0.038	95	105	0.242
13	627	0.041	100	100	0.254
14	587	0.043	110	93	0.273
15	551	0.046	120	86	0.295
16	520	0.049	130	81	0.314
17	493	0.052	140	76	.0.334
18	468	0.054	150	72	0.35
19	446	0.057	160	68.7	0.37
20	426	0.060	180	62.4	0.41
22	391	0.065	200	57.4	0.44
24	.361	0.070	250	49.1	0.52
26	336	0.076	300	43.2	0.59
28	314	0.081	350	38.8	0.65
30	296	0.086	400	35.4	0.72
35	257	0.099	500	30.9	0.82
40	228	0.111	600	27.7	0.92
45	205	0.124	800	23.4	1.09
50	187	0.136	1000	20.9	1.21
55	171	0.148	1500	17.1	1.49
60	158	0.160	2000	14.8	1.72
65	147	0.172	3000	12.1	2.10

This table is compiled from observations made at Cincinnati, St. Louis, New Orleans, Pittsburgh, Brooklyn, Philadelphia, and Boston, for records of which we are indebted to several observers. The values of the turbidities by the reciprocal scale are included in the table for convenience, but they do not form a part of the standard.

This graduation is subject to revision whenever additional data shall make it necessary, and revised rods shall be designated by the same name, but with the year of revision substituted for 1902. The revisions shall have as their basis the one hundred mark, 100 millimeters from the wire.

Near the end of the rod, at a distance of 1.2 meters from the platinum wire, a wire ring shall be placed directly above the wire, through which the observer will look, the object of the ring being to control the distance from the wire to the eye.

When the turbidity is greater than 500 the water should be diluted before the observation is made. When the turbidity is below 7 this method can not be used, and comparison should be made with the silica standard properly diluted in bottles or tubes, as described by Whipple and Jackson in Technology Quarterly, Vol. XII, No. 4, December, 1899.

The number obtained by dividing the weight of suspended matter in parts per million by the turbidity as obtained above shall be called the coefficient of fineness. If greater than unity it indicates that the matter in suspension in the water is coarser than the standard; if less than unity, that it is finer than the standard.

This standard is proposed with the idea of combining the best features of the platinum-wire and silica methods of measuring turbidities as commonly used, and of avoiding, as far as possible, the objections to each.

The wire method is most convenient as a field method. With the reciprocal scale, which until now has been used, it is open to the serious objection that the readings are not proportional to the amount of turbidity-producing matter in the water.

The silica standard is free from this objection and is more convenient as a laboratory method, but is not well adapted to field use, and is open to the objection that it is possible that the value may be changed by variations in the fineness of the silica particles composing the standard.

The standard now proposed is intended to overcome the above-mentioned defect in the platinum-wire method with the reciprocal scale, and at the same time to control the value of the silica standard. Applying it in one way or the other, it is adapted to both field and laboratory use, and the results obtained should check substantially.

Method of Making Observations

The method of making the observations by means of the platinum wire is as follows: Take a stick of wood about 5 feet long and five-eighths of an inch square, more or less, and insert a platinum wire at a point about 1 inch from the end, so that the wire will be at right angles to the stick and project at least 1 inch. The wire should be 0.04 inch or 1 millimeter in diameter; the stick is then graduated, the lines for the various turbidities being at distances from the wire shown in the table on page 2.

Observations of turbidity are taken by putting the stick into the water under examination as far as the wire can be seen; the turbidity is then read from the scale. This is most conveniently accomplished by having a second or smaller stick placed in front of the first, the end of which is brought to the water line when the wire can just be seen. Upon removing the two together the position of the smaller stick on the scale gives the turbidity.

Observations are to be taken in all cases in open air, as too high results are obtained under a roof, even with very good light; and they should preferably be taken in the middle of the day and not in direct sunlight. In case the sun is shining the observer can stand so that his shadow covers the water immediately about the stick and wire. The observations are taken with the eye

of the observer at the ring before mentioned, 1.2 meters from the wire, although some variation in this does not materially influence the result. The wire should be kept bright and clean. In case it is lost, a clean bright pin can be used until another wire can be obtained. If the surface of the water in the stream is agitated by currents, waves, etc., or if the depth is not sufficient to give the required immersion, or if for any reason observations can not be well taken from the bank, a pail or tub may be filled with water and the turbidity observations taker in it. In many cases this proced .re is preferable to measurement in a stream, but the observation must be taken immediately upon filling the vessel. The diameter of the vessel should be equal to at least twice the depth at which the wire is immersed, as otherwise the results of the reading will be affected.

When the turbidity of the water is above 500, that is, if the wire can be seen through less than 1 inch of water, the results obtained by direct measurement are not accurate. Such water should be diluted by 1, 2, or 4 volumes of clear water in the pail or tub, and thoroughly mixed. The turbidity is taken as above described, and multiplied by the ratio that the total volume of the water bears to the water in the mixture. Clear water can be obtained from a well or from any other source of water obviously clear, or nearly so. The state nent of turbidity in such cases should contain memoranda that the observations were taken in this way, and should give the amount of dilution.

If waters have a turbidity less than 7 direct reading can not be used, and indirect methods must be resorted to.

The wire method has been described first in the circular, as it is best suited to field work. Besides this method, there are two others that have commended themselves to practical use. First, the use of standards of comparison; second, the diaphanometer. These are both laboratory methods, and have been described by Mr. George G. Whipple and Daniel D. Jackson, in the Technology Quarterly, Vol. XII, No. 4, December, 1899.

Color

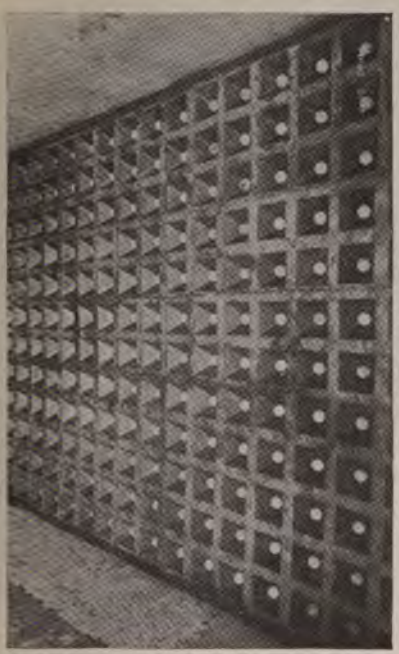
The platinum-cobalt method of measuring color, as devised by Allen Hazen, is generally considered the standard.

A standard solution which has a color of 500 shall be made by dissolving 1.246 grams potassium-platinic chloride ($PtCl_4$, $2KCl$), containing 0.5 gram platinum, and 1 gram of crystallized cobalt chloride ($CoCl_2$, $6H_2O$), containing 0.25 gram of cobalt in water, with 100 cubic centimeters concentrated hydrochloric acid, and making up to one liter with distilled water. By diluting this solution, standards shall be prepared having values of 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, and 70. The numbers correspond to the metallic platinum in the solutions in parts per million. These

shall be kept in 100 cubic centimeter Nessler jars of such diameter that the liquid shall have a depth between 20 and 25 centimeters and shall be protected from the dust. The color of a sample shall be observed by filling a similar tube with water and comparing it with the standards. The observation shall be made by looking vertically downward through the tubes upon a white surface placed at such an angle that light is reflected upward through the column of liquid. The reading shall be recorded to the nearest unit. Waters that have a color darker than 70 shall be diluted before making the comparison, in order that no difficulties may be encountered in matching the hues. Water containing matter in suspension shall be filtered until no visible turbidity remains. If the suspended matter is coarse, filter paper may be used for this purpose; if the suspended matter is fine, the use of the Berkfeld filter is recommended. The use of a Pasteur filter is to be avoided as it exerts a decolorizing action.

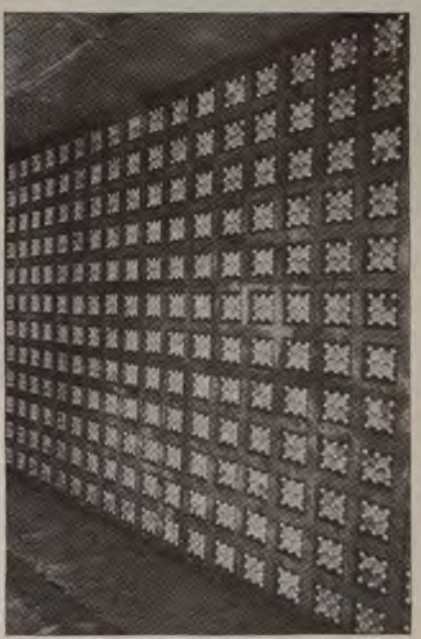
It is impracticable to carry the standard tubes above described into the field for observations, and yet field observations are of great convenience and value to the sanitary engineer, and in general to the investigations of the United States Geological Survey.

Color Standards.— Disks of colored glass have been prepared by Mr. Allen Hazen, in cooperation with the Survey, as standards for measuring color of water in the field. These disks have been rated by Mr. George C. Whipple to correspond with the platinum-cobalt standard. The color is measured by balancing the color of the water in a metallic tube with glass ends against the colors of glass disks of known value. The number on each disk represents the corresponding color of a water. This is not a new standard, but a new application of an old standard. The glass disks are rated to correspond with the platinum-cobalt color standard. The process bears the same relation to the usual laboratory process that an aneroid barometer bears to a mercurial barometer. The metallic tubes and glass standards are more portable and better adapted to field use than the Nessler tubes and color solutions heretofore used. The standards are disks of amber-colored glass, mounted with aluminum. Each disk carries two numbers. One number is over 100, and is a serial number for the purpose of identification. The other number is less than 100, and shows the color value of the disk; that is to say, the color of each disk is equal to the color of a solution of the designated number of parts per million of platinum with the required amount of cobalt to match the hue when seen in a depth of 200 millimeters. When a water comes between two disks, its value can be estimated between them by judgment. Two or more disks can be used, one behind the other, in which case their combined value is the sum of the individual values.

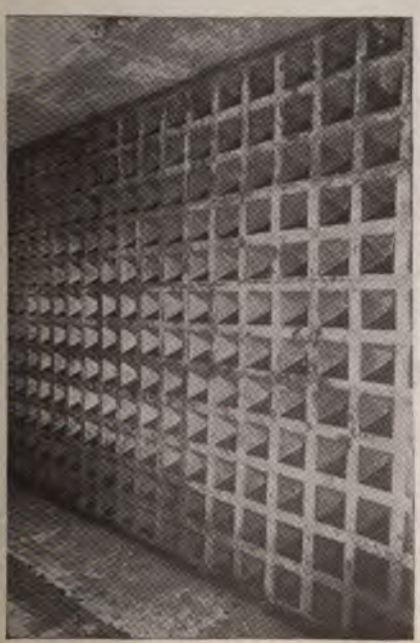


Second Stage

Fourth Stage

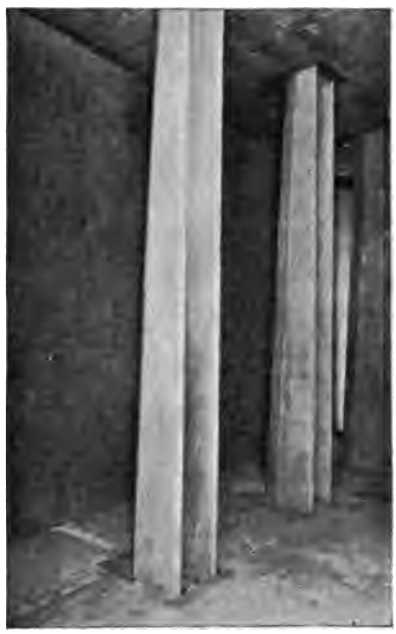


Akron, O., Filter Bottom. Improved Weston Type



First Stage

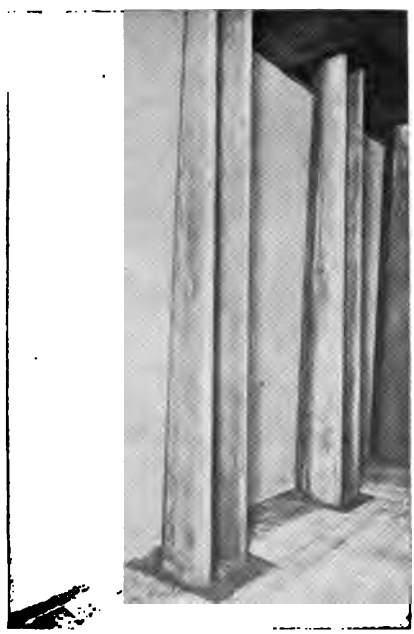
Third Stage



Seventh Stage

Fifth Stage

Akron, O., Filter Bottom



Eighth Stage

Six h Stage

By combining the disks of a series in different ways a considerable number of values can be produced, allowing the closer matching of many waters.

Filling the Tubes.—The tube, having an aluminum stopper, is to be filled with water, the color of which is to be determined. Rinse the tube once or twice by filling and emptying it. The second tube, having the clips to hold the glass disks, is made much like the one holding the water, to facilitate comparison. Theoretically, this tube should be filled with distilled water. Practically, it makes very little difference whether it is filled with distilled water or empty. Use distilled water when it is convenient to do so, and when distilled water of unquestionable quality is at hand; otherwise wipe the inside of the tube dry to prevent fogging of the glass ends, and proceed with the tube empty.

Holding the Tubes.—Hold the tubes at such distance from the eye that the sides of the tubes just cannot be seen. This occurs when the near end of the tube is 6 or 8 inches from the eye. Hold the tubes at such an angle that both can be seen at once with one eye. Good results cannot be obtained in any other way. Let the tubes change places once or twice, as sometimes the light on the right and left is not quite equal.

Background.—There should be a clear white background with a strong illumination. The best results cannot be obtained with either too little or too much light. In a gray day look at the sky near the horizon and away from the sun. In a bright day look at a piece of white paper or a tile upon which a strong light falls. The white surface may be vertical and the tubes held horizontally, or the tubes may be held at an angle directed downward toward a horizontal surface, as may be most convenient. Good results cannot be obtained by artificial light.

Turbid Water.—The colors of very turbid waters cannot be measured in this way. Slight turbidities do not interfere seriously with the results. Waters too turbid for direct observations should be filtered through thick filter paper before being tested; and in case the suspended matter causing the turbidity is fine in grain and large in amount, even this method may fail. The turbidity of water should be taken as far as possible in connection with color observation, except in cases where it is obvious from inspection that there is practically no turbidity.

Highly Colored Waters.—Some waters will be found having a higher color than can be matched by the standards. In general, waters with colors above 100 should not be matched in 200-millimeter tubes, and the results with waters having colors below 80 will be considerably more accurate than with more highly colored ones. Two procedures are possible with waters having higher colors: namely, to dilute with distilled water before measuring the color, or to use shorter

tubes. The latter procedure is the more convenient, but both are equally accurate. To measure the color with short tubes, put the highly colored water in a tube of one-half the usual length and match as usual. It is not necessary to have a short standard holder. The 200-millimeter tube can be used. After the water is matched the result is multiplied by 2. In case the color is too high to be read in a 100-millimeter tube it can be put in a 50-millimeter tube, and the result multiplied by 4. When dilution is used the highly colored water is mixed with one or more volumes of distilled water, the color matched, and the result multiplied by a corresponding factor. The tube itself can be used for measuring the colored water and the distilled water, and the mixing can be done in a tumbler or any convenient clean vessel.

Cleaning the Tubes.—Always keep the tubes clean. Take particular care of the glass ends. All the ends are removable for the purpose of cleaning, and should not be screwed on too tightly. They should be water-tight when screwed up only loosely, for if screwed on hard they may stick so as to come off with difficulty.

F. H. NEWELL,
Hydrographer.

Washington, D. C., May 1, 1902.

(2) Character of the Turbidity

In some plants located on rivers, several different characters of turbidity may be given by different tributaries. A study of these will reveal certain peculiarities in each. One may be handled to better advantage by one method and another by a different method. These differences can be found only by close observation and study and will have to be worked out at each plant by the operator, as they vary too largely to deal with in a work of this kind. A very satisfactory turbidity rod and color tube set, in neat case, may be purchased from the Builders Iron Foundry, Providence, R. I.

(3) Color

The circular of the United States Geological Survey, previously incorporated, gives the method most generally employed for determining color in modern purification works.

(4a) Free Carbonic Acid

If a drop of phenolphthaleine indicator solution be added to ten cubic centimeters of the water to be tested, it should not produce even the slightest tint of pink discoloration if free carbonic acid is present. If the water remains colorless or merely shows a milk tint, free carbonic acid may be present, but if the slightest discoloration of a pinkish shade results, free carbonic acid is not present. In case no color develops, one drop of $\frac{N}{22}$ sodium carbonate volumetric solution should be added to the sample, and if this produces a pink color, no appreciable quantity of free carbonic acid is present,

but if no color is produced, then free carbonic acid is present and a sample of the water may be subjected to test to ascertain what the amount may be.

(4b) Phenolphthaleine Test Solution

This is prepared by adding two grams of phenolphthaleine, a white powder, to one litre or one thousand c.c. of 50 per cent. grain or wood alcohol. A stronger alcohol may be used if the expense is not deterrent. When all the phenolphthaleine is dissolved, the solution should be filtered through two thicknesses of fine white filter paper and placed in a litre bottle which has previously been thoroughly cleaned with distilled water. This forms the stock solution. A dropping bottle, which may be of any style preferred by the operator, should be filled from the stock bottle, and should be used for ordinary work.

(4c) To prepare an $\frac{N}{22}$ sodium carbonate volumetric solution, the operator is referred to Sutton's Volumetric Analysis, where full instructions may be found for preparing all of the volumetric solutions. An $\frac{N}{22}$ sodium carbonate volumetric solution may be purchased from any chemical supply house such as Eimer & Amend, New York, Scientific Materials Company, Pittsburgh, or Henry Heil Chemical Company, St. Louis.

Procedure.—Fill a burette with $\frac{N}{22}$ sodium carbonate volumetric solution and adjust the meniscus to the zero mark, taking care to see that the point of the burette below the stop cock contains no air bubbles. Measure out fifty cubic centimeters of the water into a beaker and place on a piece of white paper or porcelain, or put it into a porcelain evaporating dish, add one or two drops of phenolphthaleine test solution, and then add, drop by drop, enough of the $\frac{N}{22}$ sodium carbonate volumetric solution to produce a very slight pink color. The water must be stirred after each drop has been added, until the color shows. When the color shows and remains after stirring, read the burette and note the amount of sodium carbonate volumetric solution required to produce the color. Each cubic centimeter so used corresponds to one milligram of free carbonic acid present in the water. Example: A 50 c.c. sample of water required .7 c.c. of $\frac{N}{22}$ sodium carbonate volumetric solution to show a pink color; 50 c.c. of water equal 50,000 milligrams of water, and as this required .7 c.c. of the sodium carbonate volumetric solution, each c.c. of which is equal to one milligram of free carbonic acid, it follows that if 50,000 milligrams of water contain 0.7 milligram of free carbonic acid, 1,000,000 milligrams of water would contain twenty times as much, or 14.0 parts of free carbonic acid, and hence the c.c. of volumetric solu-

tion employed multiplied by 20 gives the number of parts per million of free carbonic acid.

$0.7 \times 20 = 14$, or the number of parts per million of free carbonic acid present in the sample of water examined. The results of these titrations are usually stated in parts per million.

Normal or Monocarbonate Alkalinity

There are three kinds of alkalinity which may be present at some time or other in water where the American Steel & Wire Company's process is employed, or any other process employing lime for chemical treatment. These are caustic or hydrate alkalinity, normal or monocarbonate alkalinity, and bicarbonate alkalinity. The sum of all the alkalinities is called the total alkalinity. A water in the natural state may have two different kinds of alkalinity at the same time, and this also holds true of a water which has been treated with a caustic or hydrate. Not more than two kinds of alkalinity can ever be present in one sample of water, so if we find two we need not expect to find the third in any sample.

If a water be possessed of an alkaline reaction we are always assured that there will be present some calcium carbonate. In case the water is not of an alkaline reaction, but, on the contrary, of an acid reaction due to the presence of mineral acid, it is equally certain that there will be no carbonates of any kind present.

Indicators

In order to ascertain whether a water has an acid or alkaline reaction the chemist resorts to the use of certain indicators or test solutions. There are a large number of these indicators or test solutions, each one having its peculiar properties and uses. In addition to the test solutions used as indicators there are other indicators which are employed in the dry state. Some of these are in very common use, such for example as litmus paper, tumeric paper, and others of a similar nature.

Most of the indicators which are used in the dry state or in the form of papers are of little real value in water work, due to the fact that they are not possessed of sufficient delicacy or positiveness to be adapted for these purposes.

It will be necessary for the operator to have a working knowledge of the use of these indicators before he can use them intelligently. The reasons for their employment should be thoroughly understood, and in order that he may obtain this information we shall incorporate here a brief discussion of the substances used as indicators in this process and their peculiarities.

The meaning of the word "indicator" is almost too obvious to require explanation. A chemical indicator is one which is used to indicate the completion or beginning of a chemical reaction.

All water supplies fall in one of two classes. Thus a water may have either an acid or an alkaline

reaction. Theoretically it might have neither an alkaline nor acid reaction, but be neutral. However, no natural water supplies are ever found in the neutral state, although some of them closely approach this.

Practically all water supplies contain both acid and alkaline matters, but an acid and an alkali cannot exist in one solution at the same time. When an acid and an alkali are brought together a chemical combination occurs and salts or neutral substances are usually produced. If the quantity of alkali or base be exactly sufficient to unite with the quantity of acid present, the occurring chemical reaction is completed and neither alkali nor acid is left in excess, and the solution is therefore neutral, but if there be a slight excess of acid over that required to neutralize the alkali, the resulting solution will be possessed of an acid reaction. In case the quantity of acid is insufficient to neutralize the alkali present, there will be an excess of alkali remaining in solution and the solution will therefore be possessed of an alkaline reaction. Only in cases where the quantity of alkali and acid is exactly sufficient to neutralize each other will the result be a neutral solution, and in natural water supplies this state of affairs never occurs.

A distilled water may be produced which contains neither acid nor alkali and which is therefore neutral, and all distilled water used for chemical purposes in connection with water work should answer this requirement. Neutral substances may be dissolved in a distilled water without changing its neutrality, but if an acid or alkali be dissolved in distilled water it immediately becomes acid or alkaline in character.

In order to determine whether a given water is possessed of an acid or alkaline reaction the chemist resorts to the use of indicators as previously stated. The usefulness of these indicators depends upon their property of changing color in an acid or alkaline solution. Thus an indicator is of one color in an acid solution and of another in an alkaline solution.

Litmus

Litmus paper when touched with a drop of acid turns red, while when touched with a drop of alkali turns blue. Some indicators are colorless in the presence of an acid and assume a color when brought in contact with an alkaline solution.

All chemical indicators have certain peculiarities which render them more sensitive to certain acids or alkalies than other indicators of different chemical formation, and this is the reason why chemists use various kinds of chemical indicators. For instance, one indicator may be very sensitive to carbonic acid in solution while another may be relatively much less sensitive to this particular acid. The chemist in testing for carbonic acid would naturally use the indicator which

is best adapted to the purpose desired and most sensitive to the action of this acid. While litmus paper is one of the most commonly used indicators it is not sufficiently sensitive for water work and is therefore seldom or never used by the expert water analyst.

The large number of chemical substances found in solution in water supplies renders it necessary for the chemist to use the indicators best adapted to determine the presence of these substances.

Methyl Orange

Perhaps the indicator most generally employed in water purification methods is methyl orange. It is only within recent years that the value of this substance has become generally known. Some operators still find difficulty in using this indicator. The difficulty in its use is twofold. First, a great deal of methyl orange prepared and sold for indicator purposes is not suited for this work. An indicator to be of any value must have what is known as a definite end point; in other words, it must be very sensitive and must give its characteristic reaction, or change of color, sharply and decisively the instant the end point has been reached.

Volumetric Solutions

Very dilute volumetric chemical solutions are employed for tritration purposes, and it is necessary to measure very accurately the ntity of such chemical test solutions in order to gain the desired information. If an indicator does not react sharply when the end point has been obtained the operator may add more of the volumetric solution than is actually required and thus obtain a false reading.

Volumetric solutions are solutions of known strength, i. e., a definite volume of the solution contains a known definite volume by weight of the chemical reagent.

The operator in order to ascertain the exact degree of acidity or alkalinity of any given water takes a known measured volume of the water and places it in a proper receptacle and adds the required amount of indicator solution. If methyl orange be used as an indicator the mixture will have one of two colors, either an orange yellow shade, indicating an alkaline water, or a reddish purple shade, indicating an acid water.

In order to ascertain the amount of acid or alkali present, the operator adds an acid volumetric solution to the mixture if the water be shown to be alkaline, or an alkaline volumetric solution if the water be shown to be acid. This is applied by means of a burette. A burette is a long cylindrical glass tube of uniform diameter throughout its length. It is graduated from zero to the maximum capacity of the instrument, which is usually 50 cubic centimeters. The graduation is in units and tenths. The instrument is adjusted to the zero mark by filling

and drawing down to zero, being careful to remove all air from the tip below the glass cock. The volumetric solution is run into the measured volume of water drop by drop until the indicator shows a change of color, when the reading of the burette is taken, in order to determine the amount of volumetric solution employed to bring about the change of color. If the proper indicator has been used, one drop of an N/50 acid or alkali should be sufficient to cause a distinct change in the color of the indicator. The exact point at which this change of color begins to occur is known as the end point and it is essential that every indicator shall be capable of producing a sharp and decisive end point. If the change in the color of the indicator is not brought about by one drop of an N/50 volumetric solution, the end point cannot be said to be sharp. In case the indicator does not give the desired end point it is advisable to make up a fresh solution of indicator or to use a new source of supply.

Phenolphthaleine

Care will have to be taken in determining whether the indicator is adapted to perform the work for which it is being used, and this cannot be done unless the operator has a clear understanding of the limitation of his indicators. We are very frequently informed by those who are not well posted in this matter that certain waters are possessed of a caustic alkalinity. When asked what indicator was used to determine the causticity, the reply is almost always "phenolphthaleine." When asked how the test was made the answer is usually "by testing with phenolphthaleine."

As a matter of fact no one can tell by the use of phenolphthaleine only whether a given alkalinity is of a caustic or monocarbonate type, for the reason that the phenolphthaleine indicator solution is just as sensitive to a monocarbonate alkalinity as it is to a caustic alkalinity. In other words, if any of the monocarbonates of lime, magnesia or soda be present, the water will turn as pink under the test with phenolphthaleine as though the caustics of these bases were present. Therefore it is impossible to use this indicator for this particular purpose unless we use something else in conjunction with it.

Silver Nitrate

The only indicator in ordinary use for determining directly the presence of a caustic is that of silver nitrate solution. If a few drops of a 5 per cent. silver nitrate test solution be added to 5 cubic centimeters of the water to be tested, the formation of a yellowish or brownish yellow color indicates the presence of caustic alkalinity. If the mixture remains clear or milky white with no tinge of yellow, caustics are not present to any considerable extent. This

test with nitrate of silver, however, is not very sensitive and it does not give any information regarding the quantity of caustics present.

Caustic Alkalinity

In most instances it is desirable to know not only that caustics are present, but also to know the quantity present in any water supply, and this information cannot be obtained by the use of nitrate of silver solution. To do this we are compelled to utilize the rather significant property of phenolphthaleine. This indicator turns a purplish red if monocarbonates or caustics be present in solution, but if there be no caustics or monocarbonates and only bicarbonates, the solution remains white or milky.

Monocarbonate Alkalinity

It has also been stated that if a water containing monocarbonates be treated with carbonic acid, any monocarbonates which are present can readily be converted into bicarbonates. It has also been shown that monocarbonates of lime or magnesia when treated with sulphuric acid are converted into sulphates and carbonic acid is liberated in the reaction.

Now if we assume a solution containing ten milligrams of calcium monocarbonate alkalinity with no caustic or bicarbonate alkalinity present, it will be obvious that if we run in 5 cubic centimeters of an N/50 sulphuric acid solution which contains just exactly sufficient sulphuric acid to neutralize 5 milligrams of calcium monocarbonate, $CaCO_3$, we will have converted 5 milligrams of monocarbonate of lime into an equivalent quantity of calcium sulphate and will have liberated an equivalent quantity of carbonic acid. The carbon dioxide so liberated will unite with the other 5 milligrams of calcium monocarbonate, forming an equivalent quantity of calcium bicarbonate and there will be left in solution an alkalinity neither monocarbonate nor caustic; the entire remaining alkalinity being of the bicarbonate type.

Bicarbonate Alkalinity

With the last drop of the 5 cubic centimeters of N/50 acid so applied the color of the indicator will change and the pink color imparted by the phenolphthaleine test solution completely disappear. If we now add one drop of a saturated solution of methyl orange the solution will turn a lemon yellow, thus indicating an additional alkalinity in excess of that shown by phenolphthaleine, and the use of an additional 5 cubic centimeters of the N/50 acid will be required to neutralize the bicarbonate alkalinity created by the addition of the acid employed to discharge the color imparted in the first place by phenolphthaleine, and convert the lime contained therein into sulphate of lime. When this has been done, then the addition of another drop of the acid solution will cause the lemon yellow color imparted by the methyl orange to change to a darker shade.

End Point

A certain difficulty is experienced by some operators in detecting this change of shade. Those operators who are partially or completely color blind in respect to the yellows and reds will probably find it impracticable to use this indicator with any degree of satisfaction. Those who have a keen sense of discrimination between yellow and reds will find that the ability to discover this change becomes very acute with a little practice.

Much of the methyl orange sold for use as indicator is not suitable for this purpose and will not give a sharp end reaction, but we have never experienced any difficulty in obtaining methyl orange which gave entirely satisfactory results when we purchased Gruebler's Methyl Orange, sold as a staining agent and used for microscopical work. Although this dye is prepared for other purposes, it is eminently satisfactory for indicator purposes and is very much superior to that ordinarily prepared for use as an indicator.

Control

In all cases where an operator is attempting to use an indicator it is well to resort to the use of a "control." This "control" consists of taking the same quantity of water and placing it in another vessel identical with that in use for the test and treating it with exactly the same quantity of indicator solution. The two samples are then placed side by side, one of the two being titrated and the other being used merely for comparison in order to determine the exact point at which the color change takes place. Where there is a little difficulty in determining the end point, the ability to compare the color which is changing, or about to change, with a standard which does not change, will often enable the operator to catch the end point more accurately than if no "control" were to be used.

The change of color from lemon yellow to purplish red which is undergone in titrating against methyl orange can be more readily discerned if performed in a yellow light. A white or blue light on the contrary renders the change less easy to detect. The change in color of methyl orange which occurs when the exact end point is reached is not a complete change of color. Its first manifestation is a darkening of the shade. No perceptible change of color occurs at this point, but the peculiar darkening effect, which indicates the end point, is easily distinguishable after a little practice, and if properly performed the work is equally as satisfactory with this indicator as when lacmoid or erythrosine is employed, and the use of the latter indicators involves considerable more difficulty than that of methyl orange, inasmuch as it becomes necessary to boil the water undergoing titration when lacmoid is used and to shake it repeatedly when erythrosine is employed. It will there-

fore repay the operator to spend a little time and care in learning to distinguish the exact end point which is indicated by the methyl orange test solution.

(5) (6) (7) Alkalinities

From the preceding it will be seen that alkalinity may be of three kinds, either caustic, monocarbonate or bicarbonate; that a caustic alkalinity will give a pink color to a phenolphthaleine test solution, and that the same color will be developed by a monocarbonate alkalinity, and that therefore the fact that a water turns pink when phenolphthaleine is added does not necessarily mean that caustics are present. Thus a water may have only a caustic alkalinity or the alkalinity may be wholly monocarbonate in type or it may be a mixture of the two. Or it may be wholly of a bicarbonate type or a mixture of bicarbonate and monocarbonate alkalinity. A caustic alkalinity and a bicarbonate alkalinity cannot, however, exist in the same water, and where free carbon dioxide is found neither caustic nor monocarbonate alkalinity will be present.

From the preceding it follows that six possible conditions of alkalinity might arise. The operator must be able to determine which one of these actually exists in any given water. He must also be able to tell just how much of any type of alkalinity is present in any water as well as the total combined alkalinity of all types present.

These six possible conditions are as follows:

I. When caustic alkalinity only is present.

II. When monocarbonate alkalinity only is present.

III. When bicarbonate alkalinity only is present.

IV. When a mixture of caustic and monocarbonate alkalinity exists.

V. When a mixture of monocarbonate and bicarbonate alkalinity exists.

VI. When a mixture of bicarbonate alkalinity and free carbonic acid exists.

(I) Caustic Alkalinity

WHEN CAUSTIC ALKALINITY ONLY IS PRESENT. Samples react alkaline to both phenolphthaleine and methyl orange. One 50 c. c. sample requires just as much N/50 acid to discharge color imparted by phenolphthaleine as does another 50 c. c. sample to bring about characteristic color change imparted by methyl orange.

The volume of acid required to discharge the color due to phenolphthaleine may be called the phenolphthaleine alkalinity or indicated by the letter A, while that required to bring about the color change due to methyl orange may be called the methyl orange alkalinity or total alkalinity and designated by the letter B.

The chemical reactions are shown by the following equations, using

calcium hydrate as the caustic and sulphuric acid as the volumetric solution: $2Ca(OH)_2 + H_2SO_4 = Ca(OH)_2 + CaSO_4 + 2H_2O$. $2Ca(OH)_2 + 2H_2SO_4 = 2CaSO_4 + 4H_2O$. No carbonic acid is given off either by partial or complete neutralization of the alkalinity by acid. The volume of acid required in both samples is the same and is a measure of the caustic alkalinity present.

(II) Monocarbonate Alkalinity

WHEN MONOCARBONATE ALKALINITY ONLY IS PRESENT. Samples react alkaline to both phenolphthaleine and methyl orange. One 50 c. c. sample requires just one-half as much N/50 acid to discharge color imparted by phenolphthaleine as does another 50 c. c. sample to bring about characteristic color change imparted by methyl orange. The chemical reactions are shown by the following equations, using calcium monocarbonate as the carbonate and sulphuric acid as the volumetric solution: $2CaCO_3 + H_2SO_4 = CaH_2(CO_3)_2 + CaSO_4$. $2CaCO_3 + 2H_2SO_4 = 2CaSO_4 + 2CO_2 + 2H_2O$. Carbonic acid is given off in this reaction. When just one-half of the amount of acid required to completely neutralize the alkalinity has been added one-half of the original quantity of calcium monocarbonate has been converted into calcium sulphate and the other half into calcium bicarbonate and no calcium monocarbonate is left in solution. Calcium monocarbonate reacts alkaline to phenolphthaleine, but calcium bicarbonate reacts acid to this indicator. Hence, when all the monocarbonate has been eliminated, the color imparted by phenolphthaleine disappears. On the contrary, the monocarbonate and bicarbonate both react alkaline to methyl orange even in the presence of free carbonic acid and hence the color change of this indicator will not occur until all the monocarbonate and bicarbonate alkalinities have been converted into sulphates. Methyl orange is, however, very sensitive to free sulphuric acid and a very minute quantity of acid added after all of the carbonates have been converted into sulphates is sufficient to bring about a darkening effect of this indicator. The volume of acid required for the test by phenolphthaleine is just one-half that for methyl orange and the volume of acid necessitated by the methyl orange indicator is a measure of the monocarbonate alkalinity present.

(III) Bicarbonate Alkalinity

WHEN BICARBONATE ALKALINITY ONLY IS PRESENT. Samples react acid to phenolphthaleine but alkaline to methyl orange. Free carbonic acid does not react acid to methyl orange but free mineral acid does. As soon, therefore, as sufficient acid has been added to neutralize all the bicarbonate and convert it into sulphate the further addition of acid leaves a free mineral acid to effect the color

change. The following equations show the chemical reactions, using calcium bicarbonate as the bicarbonate and sulphuric acid as the volumetric solution:

$2CaH_2(CO_3)_2 + H_2SO_4 = CaSO_4 + CaH_2(CO_3)_2 + 2CO_2 + 2H_2O.$

$2CaH_2(CO_3)_2 + 2H_2SO_4 = 2CaSO_4 + 4CO_2 + 4H_2O.$

Here the carbonic acid begins to be given off as soon as any N/50 sulphuric acid is added and continues to increase in volume until all the bicarbonate alkalinity is destroyed. The volume of acid required is a measure of the bicarbonate alkalinity present.

(IV) Caustic and Monocarbonate Alkalinity

WHEN A MIXTURE OF CAUSTIC AND MONOCARBONATE ALKALINITY EXISTS. Samples react alkaline to both phenolphthalein and methyl orange. A 50 c. c. sample will require enough N/50 acid to neutralize all the caustic alkalinity before any free carbonic acid will be liberated. It will react alkaline to phenolphthalein to this point and in addition it will continue to react alkaline until enough additional acid has been employed to convert one-half of the monocarbonates into sulphates, and the other half into bicarbonates, when the color of the phenolphthalein will disappear. Another 50 c. c. sample will react alkaline to methyl orange until all the caustics and monocarbonates present in the original sample have been converted into sulphates, when the color change will occur. The following chemical equations show the reactions involved, using calcium hydrate and monocarbonate as the alkaline compounds and sulphuric acid as the volumetric solution:

$Ca(OH)_2 + 2CaCO_3 + H_2SO_4 = CaSO_4 + 2CaCO_3 + H_2O.$

$Ca(OH)_2 + 2CaCO_3 + 2H_2SO_4 = 2CaSO_4 + CaH_2(CO_3)_2 + 2H_2O.$

$Ca(OH)_2 + 2CaCO_3 + 3H_2SO_4 = 3CaSO_4 + 2CO_2 + 4H_2O.$

When A×2 exceeds B, the alkalinity is part caustic and part monocarbonate, and (B − A) ×2 = monocarbonate alkalinity, which we may designate by the letter C. Then B − C = caustic alkalinity.

(V) Monocarbonate and Bicarbonate Alkalinity

WHEN A MIXTURE OF MONOCARBONATE AND BICARBONATE ALKALINITY EXISTS. The procedure in this case is identical with that in the preceding section as far as obtaining readings is concerned and likewise in the designations of the readings.

In this case A × 2 is less than B.

A × 2 = monocarbonate alkalinity.

B − (A × 2) = bicarbonate alkalinity.

B = total alkalinity.

(VI) Bicarbonate and Free Carbonic Acid Alkalinity

WHEN A MIXTURE OF BICARBONATE ALKALINITY AND FREE CARBONIC ACID EXISTS. The procedure is the same as in 4 or 5, but

in this case A = 0; B = total alkalinity, which is wholly bicarbonate.

The sample to which phenolphthaleine has been added remains colorless even upon the addition of a drop or two of N/22 sodium carbonate volumetric solution. (See also page 85.)

When A is zero, it becomes necessary to test for the presence of free carbonic acid, as in this case; while all the alkalinity will be of the bicarbonate type, it may also be found that some free carbonic acid is also present, and if present it is highly desirable to know this and also to know exactly how large an amount is present. A method for determining this will be found on page 84.

It must be remembered that these alkalinities have been determined by using 50 c. c. samples. 50 c. c. of water weigh 50,000 milligrams. Each c. c. of acid used was equivalent to one milligram of alkalinity. Therefore, the results obtained are parts per 50,000. We desire these results to be stated as parts per million. Hence, we have to multiply each one of our results by 20 in order to convert them into parts per million. The reason for this is explained more fully on page 85.

(8) Rate of Filtration

It is necessary to know the rate at which the plant is working in order to be able to properly charge the chemical solution tanks. This has been previously explained. (See pages 43-44.)

(9) Effective Size of Sand

It is desirable to have this information in order to be able to anticipate what results may be looked for with any given character of coagulation going on the beds, when taken in conjunction with the rate of filtration which is employed. The effective size of the sand can usually be obtained from the filter contractor, from the record, or from the contractor furnishing the sand.

(10) Time period required for the Water to pass through the Settling Basins.

The cubic contents of the basins in cubic feet multiplied by 7.5 gives contents in gallons. This, divided by number of gallons handled daily and result multiplied by 24, gives the capacity in hours or the period of time for the water to pass through the settling basins.

With this data the operator can proceed to start the plant with fair intelligence and success. By means of the tables given herewith he can see what the limitation on the possible use of the chemicals may be. From the data given he can obtain a general idea of about the chemical dosage he wishes to apply, and can prepare his chemical solution accordingly and arrive at the size of the orifice he wishes to use.

Tables of Limitations

One part of free mineral acid in a water as reported in parts per million by titration against $\frac{N}{50}$ sodium carbonate will be neutralized

by the following quantities of alkalies:

CaO	.561
$Ca(OH)_2$	.741
$CaCO_3$	1.001
$CaH_2(CO_3)_2$	1.621
Na_2O	.621
NaOH	.800
Na_2CO_3	1.059
$NaHCO_3$	1.679

One part of free carbonic acid will be neutralized by the following quantities of alkalies:

CaO	1.275
$Ca(OH)_2$	1.684
$CaCO_3$	2.275
Na_2O	1.411
NaOH	1.820
Na_2CO_3	2.409

One part of bi-carbonate alkalinity will be neutralized or precipitated by the following:

CaO	.560
$Ca(OH)_2$	.740
Na_2O	.620
NaOH	.800

One part of monocarbonate alkalinity will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	2.219
CO_2	.439
Fe SO_4, $7H_2O$	2.776

One part of caustic alkalinity will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	2.219
CO_2	.879
Fe SO_4, $7H_2O$	2.776

One part of calcium oxide will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	3.959
CO_2	1.568
Fe SO_4, $7H_2O$	4.954

One part of Calcium Hydrate will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	2.997
CO_2	1.187
Fe SO_4, $7H_2O$	3.751

One part of sodium oxide will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	3.576
CO_2	1.417
Fe SO_4, $7H_2O$	4.476

One part of sodium hydrate will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	2.773
CO_2	1.098
Fe SO_4, $7H_2O$	3.470

One part of sodium carbonate will be neutralized by the following:

$Al_2(SO_4)_3$, $18H_2O$	2.093
CO_2	.414
Fe SO_4, $7H_2O$	2.619

In order to convert parts per million to grains per gallon or pounds per million gallons. (See pages 121, 122 and 144.)

Much nonsense has been written on the desirability of providing a table whereby the operator can determine at a glance the amount of the chemical treatment which he can employ under different conditions of turbidity, color and bacterial content of the raw water, in order to produce a given degree of purification. The removal of the turbidity may require one treatment. The removal of the bacteria may take another, while the color removal processes may require still another. The end sought in the three cases is different. One kind of turbidity may require an entirely different treatment from what another will. Apart from this, there are a dozen different factors which

Showing Combined Air and Wash Water Tank

Wilkinsburg, Pa.

Courtesy of
Pittsburgh Filter
Mfg. Co.

Aerator

are introduced by the difference in the construction of plants at different points, all of which must be taken into consideration in arriving at a proper conclusion. A table of this kind cannot be prepared which can be relied upon to give the desired information, and even if it could, there remain serious doubts as to the desirability of having such a table. An operator should be possessed of at least an average degree of intelligence. If he is not, he has mistaken his calling and should seek employment where it is not required.

If he has a fair degree of intelligence, he requires no such table, and can always use a simpler and better method to arrive at the same result in daily work, and do so much more intelligently and accurately and with a far better understanding of what he is doing than if he were to be blindly guided by any table or set of fixed and immutable rules or regulations. An operator worthy of the name is an artist in a way. He creates his results and does so as occasions warrant and conditions permit. He may produce the same result and must be able to do so under varying conditions in several different ways, and can no more be bound by rules than an artist could in producing an exquisite piece of sculpture or painting. Some initiative and imagination are required, and thought and skill must be given to the work. He must know what he wants to do, and if there is no way to do it, he must create a way. Requests of this kind seldom come from operating engineers or men who have a practical knowledge of the subject. For the beginner a better method is available and should be employed.

Chemical Difficulties

From the preceding tables, certain results from a given treatment can be approximately foretold in some respects, but there are so many factors entering into a question of this kind in practical work that any theoretical assumption must be taken very carefully and tested out to see how closely practice under the local conditions may approach the theoretical. The chemicals employed in water purification plants are not chemically pure, as the tables contemplate. Any departure from chemical purity must therefore affect the values given in the table. Worse than this, no two lots of chemicals will be of exactly the same composition, nor can one lot of chemicals be relied upon to remain of exactly the same strength if maintained in storage under average conditions for any considerable period of time. The moisture content may vary within relatively large limits, thus changing the strength. Lime in the form of quick lime is constantly losing strength and undergoing slaking and may lose a notable amount of its efficiency in thirty days' storage during hot and humid weather.

Chemical Wastage

Furthermore, some plants do not utilize all the strength of the chem-

icals employed. Some is unavoidably wasted in every plant, and the amount varies with each one of many possible different conditions. Plants with mixing chambers show a better and larger utilization of lime and less lime lost as unavailable than those without such chambers. A dozen or more other considerations enter into a problem of this kind, any one of which may upset any theoretical set of rules or values and render them unreliable.

What an operator wants to know is not how much chemical treatment may be required to meet certain hypothetical conditions which may never arise, but how to be able to meet any conditions or any set of conditions which may arise, and by the use of an average degree of intelligence, apply a treatment which will be safe, certain and economical.

In order to do this, a simple rule which can be varied as conditions demand to meet the needs of the hour and the idiosyncracies of the plant, will be all that the ordinary operator requires to meet the ordinary conditions arising in work of this kind.

Methods

In general, two plans or methods of applying the American Steel & Wire Company's process obtain. The first has for its aim the clarification of the water and a satisfactory bacterial removal. The second aims to accomplish the results of the first and in addition to soften the water either partially or wholly.

Clarification and Purification

The first plan involves less expense and trouble than the second and is the one most frequently used and advised. The broad general rule, subject to many variations as to details, necessary to handle the conditions arising under the first plan may be stated thus: Use enough lime to absorb all of the free and a small portion of the semi-combined carbonic acid and enough iron to produce a satisfactory coagulation. This one rule properly applied contains the secret of successful operation and will meet any and all possible conditions which may arise with any supply to which the process can be successfully applied.

Lime

In order to know whether enough lime has or has not been applied, it is only necessary to take a few cubic centimeters of the water after the iron and lime have been applied, let the sample stand for five minutes, and add a drop or two of phenolphthalein test solution to it. If a pink color develops immediately, enough lime has been used. If no color develops, the quantity of lime applied is too small and the lime treatment must be increased. This does not, however, inform the operator as to whether too much lime has or has not been used. This can readily be ascertained by the following procedure:

Determine the alkalinities of the raw and the filtered water. If the total alkalinity of the raw water be 50 p.p.m. or more, and if there be

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any monocarbonate alkalinity present, the amount of lime required will be very small, usually not more than ¼ g.p.g. In such cases the total alkalinity of the filtered water will not be materially different from that of the raw. If the total of the raw water be less than 50 p.p.m., the total alkalinity of the filtered water may exceed that of the raw by a few p.p.m. If the total of the raw water exceeds 50 p.p.m., the total of the filtered water should usually be from 2 to 6 p.p.m. less than that of the raw. If the total of the filtered water is 8, 10 or more p.p.m. less than that of the raw water, or if the monocarbonate alkalinity of the filtered water in such a case is more than 6 p.p.m., too much lime has been used and a partial softening action is occurring, and whenever softening occurs, some incrustation of the sand of the filter beds must be expected. If no softening is produced, and if the lime used contains only a very small amount of magnesia, not to exceed one per cent., the amount of such incrustation will be so small as to be negligible.

Softening

Where partial or complete softening is produced, incrustation to some extent must be looked for, but softening and filtration are two entirely different propositions; and while softening, even with its accompanying ills, usually pays many times its cost, including incrusting troubles, it should not be charged to filtration cost but to its own proper account. To use an ordinary filter plant as a softening plant is an abuse and necessarily involves more expense than would be the case if the plant had been properly designed to use a softening process. Even though this abuse be resorted to, the savings to the community at large may be double or triple the cost, but it is very difficult to explain and demonstrate this, and hence softening, either partial or complete, must be deemed a misuse of this method of water purification. Hence, the monocarbonate alkalinity should be kept as near 3 or 4 p.p.m. in the filtered water as is practical, and if the amount should exceed 6 p.p.m. the lime charge should be reduced. The rule is to use only sufficient lime to produce a monocarbonate alkalinity of from 3 to 6 p.p.m. in the filtered water and to use a lime which contains only a negligible quantity of magnesia. By following the preceding simple rules the process can be made available for any water for which it is adapted.

Limitations

While this is true a great many differing local conditions may affect the practical working out of the process for any one plant. Unfortunately no process yet devised will or can meet the requirements of all water supplies and all the local conditions of plant construction. There are some plants which fail to function properly, due to peculiarities in design or construction. In some cases it is a comparatively simple

Wilkinsburg Operating Floor

Louisville Operating Floor

Courtesy of Pittsburgh Filter Mfg. Co.

General View, Flint, Mich.

Flint Operating Floor

and inexpensive matter to change them over into very successful plants. In others this does not hold true. Where the arrangement of a plant is such as to render it unsuited for the application of the American Steel & Wire Company's process, while the conditions of the raw water are such as to insure a successful use of the process, it will usually pay large dividends to so change the plant as to enable it to employ the process. The advice of competent engineers should be obtained before such changes are made. The services of our Engineering Bureau-Water Purification for consultation are free to those wishing to avail themselves of the Bureau. We are glad to co-operate with engineers or cities and no expense is incurred for calling for advice from this Bureau.

Exceptions

Certain peculiarities of plans sometimes render it advisable to depart from the rules previously given in order to meet temporary conditions caused by changes in the natural water. Thus a certain type of turbidity may prove to be much more difficult to handle than the normal, due to inefficient mixing chamber action or entire lack of mixing chamber. In some instances where this has occurred a freer use of lime during the abnormal turbidity has been found advantageous. Where this obtains enough lime can be employed for a few days at a time to effect a partial softening if the total alkalinity will permit of this without bringing about a caustic alkalinity. The operator should take care to never use enough lime to show any caustic alkalinity in the filtered water, A water which contains a few parts of caustic alkalinity will not be seriously objectionable for domestic use unless lead services are used, but it is very much better to restrict the use of the lime to a point where there is no danger of this occurring. Where partial or complete softening is desired the rule previously given is changed and becomes "Use enough lime to effect the required degree of softening or use enough lime and soda ash to attain this result, and supplement the coagulation thus produced by employing only enough sulphate of iron to correct the alkalinity to the desired point."

If nothing more than clarification and bacterial removal are required, in other words, straight mechanical filtration, the coagulation is produced largely by the iron sulphate employed, but where softening is desired, most of the coagulation is produced by the use of lime or lime and soda ash, and only enough sulphate of iron is employed to supplement the coagulation obtained from the use of the lime and to correct the alkalinity to the required degree. This process is not very generally used. The chemicals required necessitate a considerable expense. Unless the plant is very carefully designed and operated trouble from incrustation must occur.

Cost

The first cost of a properly designed softening plant is very much larger than where straight mechanical filtration only is desired. The operating cost is necessarily higher. The upkeep cost is also large, and these reasons have prevented many cities from building such plants.

To use an ordinary mechanical filter plant as a softening plant can hardly be classed as a crime, but it brings to mind the lines "I blamed him, if I blamed him at all, not for the sin but the silliness of it." Some things are harder to forgive than sin, and the abuse of a mechanical filter plant comes very close to the line of criminal silliness unless it be clearly and thoroughly understood that such abuse must be paid for in upkeep and operating cost. If the price to be paid is known to be less than the benefits derived and if it is willingly and cheerfully paid, no one can have cause for complaint. Some plants have tried to accomplish this and those responsible have afterward complained of the cost and indulged in unjustifiable criticism of the plant, and the process. Even in most of these instances the benefits have many times overbalanced all the costs.

Efficiencies

A softening process must necessarily be more efficient in removing bacterial impurities than a straight mechanical filtration, and some very impure waters can be handled by this process in plants that would fail to produce equally as safe results from the use of a mechanical process only. Too often this is lost sight of even if it be known. The use of a softened water by the citizens results in a large saving to each family on laundry supplies, wear and tear on linen and other fabrics, insures a better and more nutritious value to food products cooked therein, and in general is much to be preferred for drinking purposes aside from any degree of bacterial purification which may result.

A soft water is better for drinking purposes than a hard one even where the bacterial purities of the two waters are equal. The difficulty lies in our inability to demonstrate and prove this in every instance, and to convince the public at large of the truth of the foregoing. It costs less to filter a supply than it does to both soften and filter it. The cost of this work has to be borne by the city or the company furnishing the water. The cost to the citizens is usually not increased by the process of purification. Hence the money returns direct to the purveyor show no financial returns sufficient to pay for the increased cost of softening the water. Even though the case is different from the viewpoint of the citizen, he is usually unwilling to pay a larger price for a softened water, and therefore water softening has been badly handicapped in this country.

If it were not for the difficulty of obtaining a larger price for the softened water, it is probable that a larger number of softening plants

would be built and operated. The problems involved in softening are so many that it would require more space than can be given in a volume of this kind if we were to attempt to discuss the subject at all fully. The advice of our Engineering Bureau-Water Purification Engineers may be obtained upon request for any questions arising from a demand for softening methods. We deem it best to reiterate our previous statement that except under unusual conditions it is not wise to soften water supplies with an ordinary mechanical filter plant using either the American Steel & Wire Company's process or any other process. The difficulties involved in the company's process will be less than with others, but we still advise that it should not be attempted.

The Bacteriology and Chemistry of the Process

In considering the chemistry of this subject we are obliged, on account of space, to be brief. Strictly speaking, water is water, and anything other than water found therein must be considered an impurity. Water dissolves many substances; therefore many impurities may be expected. They are divided into three general classes, gaseous, organic and mineral impurities. We shall not concern ourselves with the gaseous matters other than carbon dioxide, or as it is commonly called, carbonic acid. This gas is always present to a greater or lesser extent in some form or other in every water supply. Usually it is derived from organic matters. Organic matters are more numerous and important than those previously referred to. By organic matter we mean organized matter or substances which form or have formed a part of an organism which is or has been endowed with life. This class includes all forms of vegetable and animal matters. It necessarily includes all sewage derived from animal life and some of that from trade and manufacturing wastes.

From the viewpoint of the sanitary engineer the most important of these is that derived from animal life, containing, as it does, all of the pathogenic bacteria which are dangerous to human life. Being of microscopic size or even sub-microscopic size, bacteria cannot be seen. The clearest and most brilliant water may teem with them, but the keenest eye or sense of man cannot, unaided, gain knowledge of their presence. In order to demonstrate the fact that they are present in any given water we have to resort to various tests and procedures. The science which enables us to do this is called "Bacteriology," and the special branch of the science which deals with the species which may be expected to be found in water supplies is termed "Water Bacteriology." In this we find specialized procedures and methods which aim to give a knowledge of what any given sample of water contains, and to inform us whether such a water is safe or unsafe for human consumption.

It is impossible to deal with this subject satisfactorily in a volume of this size. Operators should be thoroughly posted on this subject and the necessary knowledge derived from the simpler text books such as "Standard Methods of Water Analysis," published by the American Public Health Association, and from "Elements of Water Bacteriology," Prescott & Winslow. These two books can be secured from any dealer in scientific literature. From the viewpoint of the practical filter operator some criticism of the last edition of "Standard Methods" is permissible. The methods given therein enable an operator to determine the quality of the water and the number of potentially pathogenic bacteria therein, but they do not permit the operator to gain all the knowledge which he requires for operating a plant.

Agar Agar

To merely determine the number of bacteria growing on agar agar at 37½ degrees centigrade, can never do this. The bacteria growing on agar agar at 37½ degrees form only a very small proportion of the total number of bacteria present in any given sample of water. Therefore, the method recommended does not enable the operator to obtain the same results which he would if he were to grow on ten or eleven per cent. gelatine at twenty degrees centigrade for forty-eight or seventy-two hours. It is admitted that the use of a ten or eleven per cent. gelatine at twenty degrees centigrade involves more difficulty than that of growing on agar at 37½ degrees, because of the special precautions which have to be taken to maintain the lower degree of temperature required for gelatine, than to produce the higher degree required for agar. In order to maintain the gelatine at twenty degrees during warm weather it is necessary to refrigerate the incubator and use regulators to keep the temperature at the desired point. This is more troublesome than the method recommended, although it is the standard method of the first edition of "Standard Methods." The new standard, while less troublesome, and while giving data to be desired from a sanitary standpoint, fails utterly in some respects to give the knowledge which the operator should and must have if he is to properly operate and control his plant.

The use of 37½ degrees of temperature in growing the bacteria inhibits the growth of common water bacteria and effectually prevents the operator from learning how many of these organisms are present. Those responsible for the change in method wished to eliminate the common water bacteria as far as possible, and to show only those of a potentially pathogenic nature. While it is highly desirable to obtain account of these bacteria, from the operator's standpoint it is equally as important to know the number of common water bacteria also present.

Operating Guide

Perhaps the sanitarian can gain a more accurate idea of the real quality of the water from the new standard than he could from the old, but he could gain a still better idea from the data obtained by using both methods. The real difficulty lies as usual, in the different requirements of sanitarian and operator, although the needs of either have a bearing on that of the other. The operator must produce a water meeting the requirements of the bacteriologist. The latter usually does not care particularly how the result is obtained; all he is concerned with is the result. The operator, on the contrary, must produce the result and must do so with the least possible chance of failure. To do this he must keep his plant in the very best possible condition. He must know as soon as possible when anything *begins* to go wrong. If he is relying on the bacteriologist to give him results, and the bacteriologist reports only on bacterial growths on agar at 37½ degrees C., the operator cannot know from these results when his plant *begins* to go wrong. The first thing he knows is that it *has* gone wrong. By the time he learns this the plant may have gone so far astray that the operator may find it difficult to bring it back. Usually the first indication of a falling off in efficiency in the plant is obtained from a rise in the count of the common water bacteria in the filtered water. This may occur a day, a week, or a month before the trouble develops sufficiently to manifest its results in a falling off in the pathogenic efficiency. If the operator has a gelatine count at twenty degrees to guide him, the falling off in efficiency may be ascertained days or weeks earlier and the moment that this decrease in efficiency is manifest, he can take steps to ascertain the trouble and stop it long before the trouble becomes sufficiently pronounced to show itself by a lowering of the pathogenic efficiency.

Gelatine Count

The gelatine count is really of much greater importance to the operator than the method recommended in the last edition of "Standard Methods," and he is justified in demanding it. If he cannot get it in any other way, he should insist on being supplied with the requisite apparatus and learn to do the work himself. It is not difficult, and full instructions may be found in the first edition of "Standard Methods of Water Analysis" or in "Elements of Water Bacteriology," Prescott & Winslow, of the edition of 1904. Most, if not all, of the danger from a water supply is inherent in its bacterial content, and without a knowledge of this subject we must remain largely in doubt as to the degree of danger attending the use of any given water. Therefore, the organic matter present in any supply becomes a matter of the greatest moment and importance.

Pipe Gallery, Avalon, Md.

Commercial Water Softener

Courtesy of P. F. Mfg. Co.

Chemical Preparation Room, Chisholm, Minn.

Operating Floor, Minneapolis

Samples

It may be well to insert a word of caution in regard to the taking of samples for bacterial analysis and the handling of the same up to the time of plating out. Too little care in the technique of this very important matter is often displayed by bacterial workers or operators who are permitted to do the sampling. Carelessness in collecting or handling bacterial samples is often responsible for results which are neither anticipated or correct. Sometimes this carelessness is only due to lack of knowledge and in these cases a more thorough knowledge of the necessities will correct the carelessness.

It has been proven that one fly may carry thousands of bacteria on its feet. About thirty billion of the smaller species might be crowded into a drop of water one sixteenth of an inch in diameter. A speck of dirt too small to be seen may be crowded with thousands of them. A careless touch of a finger to the stopper of a bottle may convey thousands and the sample be so contaminated from the stopper of the bottle that it is worthless. Hence too great care cannot be taken in collecting the water sample for bacterial analysis.

Sample bottles should be carefully cleaned and washed. After this they should be well dried. They should be no larger than is ssary. In our laboratory we the best quality of Bohemian glass, salt or wide mouthed bottle, with glass stopper, and of four-ounce capacity. The stoppers are placed very loosely in the bottle and the bottle and stopper placed inside a well made copper can, which is tin lined and almost hermetically tight. Both the can and the cover of the can are made of one piece of copper, without a seam or joint. The cover is one-half inch deep so the can when sterilized with the bottle inside and the cover of the can in place can be maintained in an upright position in a case for months if necessary and still remain sterile and fit for use.

When required for use the cover of the can should be carefully removed and the bottle withdrawn, taking care not to permit the fingers to touch the stopper except on top, or the bottle near the lip of the same. The bottle is held upside down and the stopper carefully removed, the sample taken, stopper replaced and the bottle returned to the can and the cover put on the can. The entire operation should be conducted with the greatest care and speed which can be safely employed, so as to minimize the danger of contaminating the sample accidentally. If there is any doubt mark the can as lost and take another sample. Never plate out a sample about which there is the least doubt.

Plating

In plating, get everything in readiness before opening the can

containing the sample, withdraw the bottle with same care as was used in taking the sample, remove the stopper and lift the required amount of water from the open bottle immediately with a sterilized pipette. Draw down to the zero mark and lift the cover of the Petri dish on one side high enough to permit the end of the pipette to be introduced between the cover and the dish, allow the desired amount of water to run out of the pipette into the dish, withdraw the pipette and lower the cover of the same.

Always follow the same routine and plate the sample for bacterial count before planting another sample for gas formers or other use. After the water has been placed in the Petri dish, the gelatin or agar media in which the growth is to be made should be poured into the dish and the mixture of media and water quickly and completely made by rapidly moving the dish with a rotary motion until the water and media have perfectly mixed and appears to be homogeneous, when the plate or dish should be placed on the cooling slab and allowed to solidify.

In pouring the media into the dish certain precautions must be observed. The gelatin or agar media must be melted before the water sample has been run from the pipette into the dish. This media is contained in test tubes which are plugged with cotton. Before pouring, the tube should be taken in one hand, and the cotton plug and the end of the tube be burned off in the heat of a gas flame from a bunsen burner. The cotton fires quickly and care must be taken to stop the fire before the plug is consumed or burned to a point where it cannot be easily removed from the tube without touching the lip of the tube. After the plug is removed it is well to pass the open end of the tube through the flame of the bunsen burner once or twice to make sure the lip of the tube is sterile and will not contaminate the media when it is poured from the tube to the dish.

When this has been done, again lift one side of the cover of the Petri dish, introduce the open end of the test tube between the cover and the dish, pour the contents of the tube into the dish and lower the cover. It is not necessary or advisable to try to pour all the media from the tube into the dish. A small portion left in the tube will do no harm and it is well to expedite the whole operation as much as possible so as to minimize the danger of contaminating the sample. Planting should always be done in a room where there are no air currents and where there is as little dust as possible. All apparatus used must be carefully sterilized before using and after sterilization must be kept from any possible chance of contamination until ready for use. Never permit a piece of apparatus which has been sterilized to come in contact with the atmosphere if possible and when it is necessary to so

expose it be sure to shorten the time of such exposure as much as possible.

Control

When plating out one or more bacterial samples it is always well to plate a control at the same time. The use of the control is to check the accuracy of the technique of the work. Our method of doing this is to take a Petri dish and place it with the others which are to be used in plating out. When this dish is reached, a pipette which has been sterilized is introduced into the dish exactly as though a water sample was being placed therein instead of only the empty pipette. The pipette is held in the dish about the same length of time as in the other dishes. A tube of media is burned and poured into the dish exactly as though a water sample had been placed in the dish. In fact exactly the same procedure is used as though a regular sample was to be planted except the pipette is handled without any water being taken into the pipette.

More than one control may be used if the work is being done under new or unusual conditions. The number of colonies found on the control plate, which is incubated exactly as the regular plates, will give a line on the accuracy of the work and gives the worker a feeling of security in the results. The control should show no colonies if the work is properly done.

Mineral Matters

Mineral matters, on the contrary, do not ordinarily cause acute illness. How far they may be responsible for some chronic complaints we are unable to positively affirm, but the weight of public opinion lies very largely against the domestic use of hard waters, and while public opinion is not always a safe guide, it seems probable that in this particular instance it is well founded, and the use of hard waters may therefore be deemed objectionable.

Hard Water

By a hard water is meant a water containing enough mineral or acid matter to render it difficult to produce a lather with soap. Not all mineral matters have this property, but some of them do, and it is these hardening compounds which render a water hard. Thus, a water containing calcium or magnesium compounds or acids in a free state will be rendered hard to the extent of the hardening compounds contained therein. These hardening substances may be neutralized or removed by suitable chemical treatment

Scale

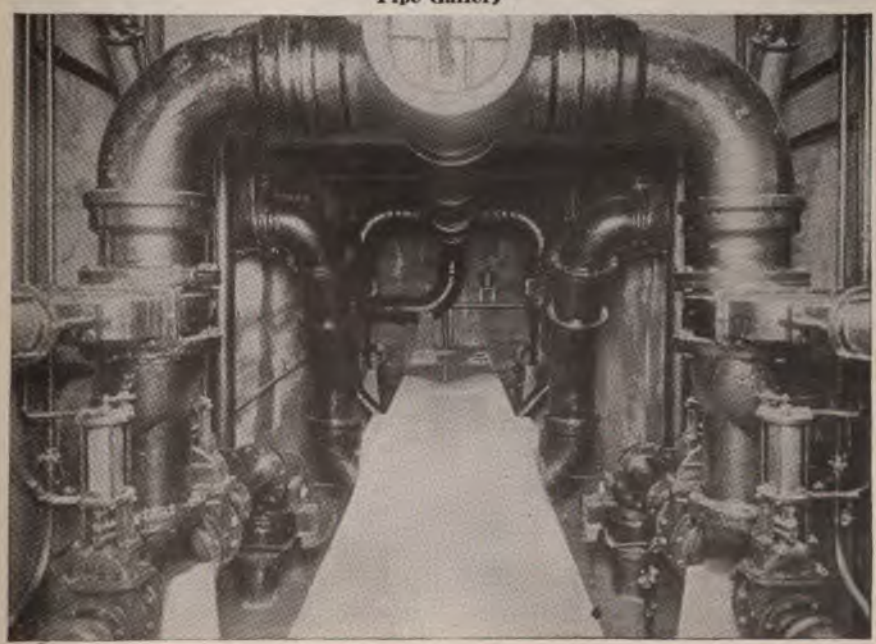
When hard water is evaporated in a vessel of any kind a scale or deposit is left in the vessel. This scale is the mineral matter carried by the water either in solution in suspension, or in solution and suspension. Boiler scale comes from the same source. A chemical analysis of a water informs us regarding the amount of scale forming sub-

General View

Waco, Texas

Courtesy of
P. F. Mfg. Co.

Pipe Gallery



stances present. and may be of great interest in the problem of properly purifying any given supply. A rather brief survey of this interesting phase of the subject follows. From an unpublished work on the subject we abstract some of the following material. The table given below gives the name of the atomic substances, their symbols and weights. By an atomic substance we mean a substance which, up to the present time, cannot, with the knowledge at hand, be converted into simpler substances. This table is used in calculating the following tables. The atomic weights have, in some instances, been slightly changed since the calculations for the following tables were made, but not sufficiently to vitiate results given.

Table No. 4
International Atomic Weights

Substances	Atomic Symbol	Atomic Weight	Substances	Atomic Symbol	Atomic Weight
Aluminum	Al.	27.1	Neodymium	Nd.	143.6
Antimony	Sb.	120.2	Neon	Ne.	20.0
Argon	A.	39.9	Nickel	Ni.	58.7
Arsenic	As.	75.0	Nitrogen	N.	14.01
Barium	Ba.	137.4	Osmium	Os.	191.0
Bismuth	Bi.	208.0	Oxygen	O.	16.0
Boron	B.	11.0	Palladium	Pd.	106.5
Bromine	Br.	79.96	Phosphorus	P.	31.0
Cadmium	Cd.	112.4	Platinum	Pt.	194.8
Caesium	Cs.	132.9	Potassium	K.	39.15
Calcium	Ca.	40.1	Praseodymium	Pr.	140.50
Carbon	C.	12.0	Radium	Rd.	225.0
Cerium	Ce.	140.25	Rhodium	Rh.	103.0
Chlorine	Cl.	35.45	Rubidium	Rb.	85.5
Chromium	Cr.	52.1	Lithium	Li.	7.03
Cobalt	Co.	59.0	Ruthenium	Ru.	101.7
Columbium	Cb.	94.0	Samarium	Sa.	150.3
Copper	Cu.	63.6	Scandium	Sc.	44.1
Erbium	Er.	166.0	Selenium	Se.	79.2
Europium	Eu.	152.0	Silicon	Si.	28.4
Fluorine	F.	19.0	Silver	Ag.	107.93
Gadolinium	Gd.	156.0	Sodium	Na.	23.05
Gallium	Ga.	70.0	Strontium	Sr.	87.6
Germanium	Ge.	72.5	Sulphur	S.	32.06
Glucinum	Gl.	9.1	Tantalum	Ta.	181.00
Gold	Au.	197.2	Tellurium	Te.	127.6
Helium	He.	4.0	Terbium	Tb.	159.2
Hydrogen	H.	1.008	Thallium	Tl.	204.1
Indium	In.	115.0	Thorium	Th.	232.2
Iodine	I.	126.97	Thulium	Tm.	171.0
Iridium	Ir.	193.0	Tin	Sn.	48.1
Iron	Fe.	55.9	Tungsten	W.	184.0
Krypton	Kr.	81.8	Uranium	U.	238.5
Lanthanum	La.	138.9	Vanadium	V.	51.2
Lead	Pb.	206.9	Xenon	Xe.	128.0
Magnesium	Mg.	24.36	Ytterbium	Yb.	173.0
Manganese	Mn.	55.0	Yttrium	Yt.	89.0
Mercury	Hg.	200.0	Zinc	Zn.	65.4
dybdenum	Mo.	96.0	Zirconium	Zr.	90.6

The following table gives the name of the substances, the chemical formula and the chemical weight of the chemical compounds found in water or used to treat it for purification purposes:

Table No. 5

Substances	Chemical Formula	Chemical Weight
Alumina Oxide	Al_2O_3	102.20
Alumina Hydrate	$Al_2(OH)_6$	156.20
Alumina Sulphate, Anhydrous	$Al_2(SO_4)_3$	342.38
Alumina Sulphate	$Al_2(SO_4)_3$, 18 H_2O	666.38
Barium Oxide	BaO	153.40
Barium Hydrate	$Ba(OH)_2$	171.40
Barium Carbonate	$BaCO_3$	197.40
Barium Chloride, Anhydrous	$BaCl_2$	208.30
Barium Chloride	$BaCl_2$, 2 H_2O	244.30
Barium Sulphate	$BaSO_4$	233.46
Calcium Oxide	CaO	56.10
Calcium Hydrate	$Ca(OH)_2$	74.10
Calcium Monocarbonate	$CaCO_3$	100.10
Calcium Bicarbonate	$Ca\ H_2(CO_3)_2$	162.10
Calcium Chloride, Anhydrous	$CaCl_2$	111.00
Calcium Fluoride	CaF_2	78.10
Calcium Hypochlorite	$Ca(ClO_2) + CaCl_2 + 2H_2O$	290.00
Calcium Nitrate	$Ca(NO_3)_2$	164.12
Tri Calcium Phosphate	$Ca_3(PO_4)_2$	310.30
Calcium Silicate	$CaSiO_3$	116.50
Calcium Sulphate	$CaSO_4$	136.16
Carbonic Acid	CO_2	44.00
Copper Oxide, Cupric	CuO	79.60
Copper Hydrate, Cupric	$Cu(OH)_2$	97.60
Copper Chloride, Cupric	$CuCl_2$, $2H_2O$	170.50
Copper Sulphate, Cupric, Anhydrous	$CuSO_4$	159.66
Copper Sulphate, Cupric	$CuSO_4$, 5 H_2O	249.66
Ferric Oxide	Fe_2O_3	159.80
Ferric Hydrate	$Fe(OH)_3$	106.90
Ferrous Oxide	FeO	71.90
Ferrous Hydrate	$Fe(OH)_2$	89.90
Ferrous Carbonate	$FeCO_3$	115.90
Ferric Chloride, Anhydrous	$FeCl_3$	162.25
Ferric Chloride	$FeCl_3$, 6 H_2O	270.25
Ferrous Chloride, Anhydrous	$FeCl_2$	156.80
Ferrous Chloride	$FeCl_2$, 4 H_2O	228.80
Ferric Sulphate	$Fe_2(SO_4)_3$	399.98
Ferrous Sulphate, Anhydrous	$FeSO_4$	151.96
Ferrous Sulphate	$FeSO_4$, 7 H_2O	277.96
Hydrochloric Acid	HCl	36.45
Magnesium Oxide	MgO	40.36
Magnesium Hydrate	$Mg(OH)_2$	58.36
Magnesium Monocarbonate	$MgCO_3$	84.36
Magnesium Bicarbonate	$MgH_2(CO_3)_2$	146.36
Magnesium Chloride	$MgCl_2$	95.26
Magnesium Nitrate	$Mg(NO_3)_2$	148.38
Magnesium Phosphate, Tri	$Mg_3(PO_4)_2$	263.08
Magnesium Pyrophosphate	$Mg_2P_2O_7$	222.72
Magnesium Sulphate	$MgSO_4$	120.42
Phosphorus Pentoxide	P_2O_5	142.00

Table No. 5—Continued

Substances	Chemical Formula	Chemical Weight
Silicon Dioxide	SiO_2	60.40
Sodium Oxide	Na_2O	62.10
Sodium Hydrate	$NaOH$	40.05
Sodium Monocarbonate, Anhydrous	Na_2CO_3	106.10
Sodium Monocarbonate	Na_2CO_3, 10 H_2O	286.10
Sodium Bicarbonate	$NaHCO_3$	84.05
Sodium Chloride	$NaCl$	58.50
Sodium Fluoride	NaF	42.05
Sodium Nitrate	$NaNO_3$	85.06
Sodium Nitrite	$NaNO_2$	69.06
Sodium Phosphate (Di Sodium Hydrogen), Anhydrous	Na_2HPO_4	142.10
Sodium Phosphate (Di Sodium Hydrogen)	Na_2HPO_4, 12 H_2O	358.10
Sodium Phosphate (Tri Sodium) Anhydrous	Na_3PO_4	164.15
Sodium Phosphate (Tri Sodium)	Na_3PO_4, 12 H_2O	380.15
Sodium Sulphate, Anhydrous	Na_2SO_4	142.16
Sodium Sulphate	Na_2SO_4, 10 H_2O	322.16
Sulphuric Acid	H_2SO_4	98.06
Sulphuric Acid, Anhydrous	SO_3	80.06
Water	H_2O	18.00

Reactions

The chemical reactions occurring in water purification work are shown in the following:

Reactions of Aluminum Sulphate

$Al_2(SO_4)_3$, 18 H_2O + 3BaO = $Al_2(OH)_6$ + 3 $BaSO_4$ + 15 H_2O.

$Al_2(SO_4)_3$, 18 H_2O + 3Ba $(OH)_2$ = $Al_2(OH)_6$ + 3 $BaSO_4$ + 18 H_2O.

$Al_2(SO_4)_3$, 18 H_2O + 3CaO = $Al_2(OH)_6$ + 3 $CaSO_4$ + 15 H_2O.

$Al_2(SO_4)_3$, 18 H_2O + 3Ca$(OH)_2$ = $Al_2(OH)_6$ + 3$CaSO_4$ + 18 H_2O.

$Al_2(SO_4)_3$, 18 H_2O + 3$CaCO_3$ = $Al_2(OH)_6$ + 3$CaSO_4$ + 15 H_2O + 3CO_2.

$Al_2(SO_4)_3$, 18 H_2O + 3$CaH_2(CO_3)_2$ = $Al_2(OH)_6$ + 3$CaSO_4$ + 18 H_2O + 6CO_2.

$Al_2(SO_4)_3$, 18 H_2O + 3$Mg(OH)_2$ = $Al_2(OH)_6$ + 3$MgSO_4$ + 18 H_2O.

$Al_2(SO_4)_3$, 18 H_2O + 3$MgCO_3$ = $Al_2(OH)_6$ + 3$MgSO_4$ + 15 H_2O + 3CO_2.

$Al_2(SO_4)_3$, 18 H_2O + 3$MgH_2(CO_3)_2$ = $Al_2(OH)_6$ + 3$MgSO_4$ + 18 H_2O + 6CO_2.

$Al_2(SO_4)_3$, 18 H_2O + 3Na_2O = $Al_2(OH)_6$ + 3Na_2SO_4 + 15 H_2O

$Al_2(SO_4)_3$, 18H_2O + 3$(NaOH)_2$ = $Al_2(OH)_6$ + 3Na_2SO_4 + 18H_2O.

$Al_2(SO_4)_3$, 18H_2O + 3Na_2CO_3 = $Al_2(OH)_6$ + 3Na_2SO_4 + 15H_2O + 3CO_2.

$Al_2(SO_4)_3$, 18H_2O + 3Na_2CO_3, 10H_2O = $Al_2(OH)_6$ + 3Na_2SO_4 + 25H_2O + 3CO_2.

$Al_2(SO_4)_3$, 18H_2O + 3$(NaHCO_3)_2$ = $Al_2(OH)_6$ + 3Na_2SO_4 + 18H_2O + 6CO_2.

$Al_2(SO_4)_3$, 18H_2O + 3$(NaF)_2$ = Al2F_6 + 3Na_2SO_4 + 18H_2O.

$Al_2(SO_4)_3$, 18H_2O + 2Na_2PO_4, 12H_2O = $Al_2(PO)_4$ + 3Na_2SO_4 + 30H_2O.

Reactions of the Barium Compounds

$3BaO + Al(SO_4)_3, 18H_2O = 3BaSO_4 + Al_2(OH)_6 + 15H_2O.$

$BaO + CaH_2(CO_3)_2 = BaCO_3 + CaCO_3 + H_2O.$

$BaO + CaSO_4 + H_2O = BaSO_4 + Ca(OH)_2.$

$BaO + CO_2 = BaCO_3.$

$BaO + FeSO_4, 7H_2O_4 = BaSO_4 + Fe(OH)_2 + 6H_2O.$

$BaO + MgCO_3 + H_2O = BaCO_3 + Mg(OH)_2.$

$BaO + MgH_2(CO_3)_2 = BaCO_3 = MgCO_3 + H_2O.$

$BaO + MgSO_4 + H_2O = BaSO_4 + Mg(OH)_2.$

$BaO + Na_2CO_3 + H_2O = BaCO_3 + 2NaOH.$

$BaO + 2NaHCO_3 = BaCO_3 + Na_2CO_3 + H_2O.$

$BaO + Na_2SO_4 + H_2O = BaSO_4 + 2NaOH.$

$BaO + SO_3 = BaSO_4.$

$BaO + H_2SO_4 = BaSO_4 + H_2O.$

$3Ba(OH)_2 + Al_2(SO_4)_3, 18H_2O = 3BaSO_4 + Al_2(OH)_6 + 18H_2O.$

$Ba(OH)_2 + CaH_2(CO_3)_2 = BaCO_3 + CaCO_3 + 2H_2O.$

$Ba(OH)_2 + CaSO_4 = BaSO_4 + Ca(OH)_2.$

$Ba(OH)_2 + CO_2 = BaCO_3 + H_2O.$

$Ba(OH)_2 + FeSO_4, 7H_2O = BaSO_4 + 7H_2O.$

$Ba(OH)_2 + MgCO_3 = BaCO_3 + Mg(OH)_2.$

$Ba(OH)_2 + MgH_2(CO_3)_2 = BaCO_3 + MgCO_3 + 2H_2O.$

$Ba(OH)_2 + MgSO_4 = BaSO_4 + Mg(OH)_2.$

$Ba(OH)_2 + Na_2CO_3 = BaCO_3 + 2NaOH.$

$Ba(OH)_2 + 2NaHCO_3 = BaCO_3 + Na_2CO_3 + 2H_2O.$

$3Ba(OH)_2 + 2Na_2PO_4, 12H_2O = Ba_3(PO_4)_2 + 6NaOH + 24H_2O.$

$Ba(OH)_2 + Na_2SO_4 = BaSO_4 + 2NaOH.$

$Ba(OH)_2 + SO_3 = BaSO_4 + H_2O.$

$Ba(OH)_2 + H_2SO_4 = BaSO_4 + 2H_2O.$

$3BaCl_2, 2H_2O + Al_2(SO_4)_3 = 3BaSO_4 + Al_2Cl_6 + 2H_2O.$

$BaCl_2, 2H_2O + CaSO_4 = BaSO_4 + CaCl_2 + 2H_2O.$

$BaCl_2, 2H_2O + FeSO_4, 7H_2O = BaSO_4 + FeCl_2 + 9H_2O.$

$BaCl_2, 2H_2O + MgSO_4 = BaSO_4 + MgCl_2 + 2H_2O.$

$3BaCl_2, 2H_2O + 2Na_2PO_4, 12H_2O = Ba_3(PO_4)_2 + 6NaCl + 24H_2O.$

$BaCl_2, 2H_2O + Na_2SO_4 = BaSO_4 + 2NaCl + 2H_2O.$

$BaCl_2, 2H_2O + SO_3 = BaSO_4 + 2HCl + H_2O.$

$BaCl_2, 2H_2O + H.SO_4 = BaSO_4 + 2HCl + 2H_2O.$

Reactions of the Calcium Compounds

$3Ca(OH)_2 + Al_2(SO_4)_3, 18H_2O = 3CaSO_4 + Al_2(OH)_6 + 18H_2O.$

$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$

$Ca(OH)_2 + 2CO = CaH_2(CO_3)_2.$

$Ca(OH)_2 + CaH_2(CO_3)_2 = 2CaCO_3 + 2H_2O.$

$Ca(OH)_2 + CuSO_4, 5H_2O = CaSO_4 + Cu(OH)_2 + 5H_2O.$

$Ca(OH)_2 + FeSO_4, 7H_2O = CaSO_4 + Fe(OH)_2 + 7H_2O.$

$Ca(OH)_2 + 2H_2Cl = CaCl_2 + 2H_2O.$

$Ca(OH)_2 + MgCO_3 = CaCO_3 + Mg(OH)_2.$

$Ca(OH)_2 + MgH_2(CO_3)_2 = CaCO_3 + MgCO_3$.

$Ca(OH)_2 + Na_2CO_3 = CaCO_3 + 2NaOH$.

$Ca(OH)_2 + aNaHCO_3 = CaCO_3 + Na_2CO_3 + 2H_2O$.

$Ca(OH)_2 + 2NaF = CaF_2 + 2NaOH$.

$3Ca(OH)_2 + 2Na_2PO_4, 12H_2O = Ca_3(PO_4)_2 + 6NaOH + 24H_2O$.

$Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O$.

$3CaCO_3 + Al_2(SO_4)_3, 18H_2O = 3CaSO_4 + Al_2(OH)_6 + 3CO_2 + 15H_2O$.

$CaCO_3 + Ba(OH)_2 = Ca(OH)_2 + BaCO_3$.

$CaCO_3 + BaCl_2, 2H_2O = CaCl_2 + BaCO_3 + 2H_2O$.

$CaCO_3 + CO_2 + H_2O = CaH_2(CO_3)_2$.

$CaCO_3 + CuSO_4, 5H_2O = CaSO_4 + CuCO_3 + 5H_2O$.

$CaCO_3 + FeSO_4, 7H_2O = CaSO_4 + FeCO_3 + 7H_2O$.

$CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$.

$CaCO_3 + 2NaF = CaF_2 + Na_2CO_3$.

$3CaCO_3 + 2Na_2PO_4, 12H_2O = Ca_3(PO_4)_2 + 3Na_2CO_3 + 24H_2O$.

$CaCO_3 + H_2SO_4 = CaSO_4 + CO_2 + H_2O$.

$3CaH_2(CO_3)_2 + Al_2(SO_4)_3, 18H_2O = 3CaSO_4 + Al_2(OH)_6 + 3CO_2 + 21H_2O$.

$CaH_2(CO_3)_2 + Ba(OH)_2 = CaCO_3 + BaCO_3 + 2H_2O$.

$CaH_2(CO_3)_2 + BaCl_2, 2H_2O = CaCl_2 + BaCO_3 + CO_2 + 4H_2O$.

$CaH_2(CO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$.

$CaH_2(CO_3)_2 + CuSO_4, 5H_2O = CaSO_4 + CuCO_3 + Co_2 + 6H_2O$.

$CaH_2(CO_3)_2 + FeSO_4, 7H_2O = CaSO_4 + 2CO_2 + 8H_2O$.

$CaH_2(CO_3)_2 + 2HCl = CaCl_2 + 2CO_2 + 2H_2O$.

$CaH_2(CO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O$.

$CaH_2(CO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaHCO_3$.

$CaH_2(CO_3)_2 + 2NaF = CaF_2 + Na_2CO_3 + 2H_2O$.

$3CaH_2(CO_3)_2 + 2Na_2PO_4, 2H_2O = Ca_3(PO_4)_2 + 6NaHCO_3 + 24H_2O$.

$CaH_2(CO_3)_2 + H_2SO_4 = CaSO_4 + 2CO_2 + 2H_2O$.

$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$.

$CaCl_2 + 2NaF = CaF_2 + 2NaCl$.

$3CaCl_2 + 2Na_2PO_4, 12H_2O = Ca_3(PO_4)_2 + 6NaCl + 24H_2O$.

$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$.

$CaSO_4 + 2NaF = CaF_2 + Na_2SO_4$.

$3CaSO_4 + 2Na_2PO_4, 12H_2O = Ca_3(PO_4)_2 + 3Na_2SO_4 + 24H_2O$.

Reactions of Carbonic Acid or Carbon Dioxide

$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$.

$2CO_2 + Ca(OH)_2 = CaH_2(CO_3)_2$.

$CO_2 + H_2O + CaCO_3 = CaH_2(CO_3)_2$.

$CO_2 + 2NaOH = Na_2CO_3 + H_2O$.

$2CO_2 + 2NaOH = 2NaHCO_3$.

$CO_2 + H_2O + Na_2CO_3 = 2NaHCO_3$.

$CO_2 + 2Na_2PO_4, 12H_2O = 2Na_2HPO_4 + Na_2CO_3 + 23H_2O$.

Reaction of Copper (Cupric) Sulphate

$CuSO_4$, $5H_2O$ + $Ba(OH)_2$ = $BaSO_4$ + $Cu(OH)_2$ + $5H_2O$.

$CuSO_4$, $5H_2O$ + $Ca(OH)$ = $Cu(OH)_2$ + $CaSO_4$ + $5H_2O$.

$CuSO_4$, $5H_2O$ + $CaCO_3$ = $CuCO_3$ + $CaSO_4$ + $5H_2O$.

$CuSO_4$, $5H_2O$ + $CaH_2(CO_3)_2$ = $CuCO_3$ + $CaSO_4$ + CO_2 + $6H_2O$.

$CuSO_4$, $5H_2O$ + $Mg(OH)_2$ = $Cu(OH)_2$ + $MgSO_4$ + $5H_2O$.

$CuSO_4$, $5H_2O$ + $MgCO_3$ = $CuCO_3$ + $MgSO_4$ + $5H_2O$.

$CuSo_4$, $5H_2O$ + $MgH_2(CO_3)_2$ = $CuCO_3$ + $MgSO_4$ + CO_2 + $6H_2O$.

$CuSO_4$, $5H_2O$ + $2NaOH$ = $Cu(OH)_2$ + Na_2SO_4 + $5H_2O$.

$CuSO_4$, $5H_2O$ + Na_2CO_3 = $CuCO_3$ + Na_2SO_4 + $5H_2O$.

$CuSO_4$, $5H_2O$ + $2NaHCO_3$ = $CuCO_3$ + Na_2SO_4 + CO_2 + $6H_2O$.

Reactions of Iron Sulphate

$FeSO_4$, $7H_2O$ + $Ba(OH)_2$ = $Fe(OH)_2$ + $BaSO_4$ + $7H_2O$.

$FeSO_4$, $7H_2O$ + $BaCl_2$, $2H_2O$ = $FeCl_2$ + $BaSO_4$ + $9H_2O$.

$FeSO_4$, $7H_2O$ + $Ca(OH)_2$ = $Fe(OH)_2$ + $CaSO_4$ + $7H_2O$.

$FeSO_4$, $7H_2O$ + $CaCO_3$ = $FeCO_3$ + $CaSO_4$ + $7H_2O$.

$FeSo_4$, $7H_2O$ + $CaH_2(CO_3)_2$ = $FeH_2(CO_3)_2$ + $CaSO_4$ + $8H_2O$.

$FeSO_4$, $7H_2O$ + $Mg(OH)_2$ = $Fe(OH)_2$ + $MgSO_4$ + $7H_2O$.

$FeSO_4$, $7H_2O$ + $MgCO_3$ = $FeCO_3$ + $MgSO_4$ + $7H_2O$.

$FeSO_4$, $7H_2O$ + $MgH_2(CO_3)_2$ = $FeH_2(CO_3)_2$ + $8H_2O$.

$FeSO_4$, $7H_2O$ + $2NaOH$ = $Fe(OH)_2$ + Na_2SO_4 + $7H_2O$.

$FeSO_4$, $7H_2O$ + Na_2CO_3 = $FeCO_3$ + Na_2SO_4 + $7H_2O$.

$FeSO_4$, $7H_2O$ + $2NaHCO_3$ = $FeH_2(CO_3)_2$ + Na_2SO_4 + $7H_2O$.

$FeSO_4$, $7H_2O$ + $2NaF$ = FeF_2 + Na_2SO_4 + $7H_2O$.

$3FeSO_4$, $7H_2O$ + $2Na_2PO_4$, $12H_2O$ = $Fe_3(PO_4)_2$ + $3Na_2SO_4$ + $45H_2O$.

Reactions of the Magnesium Compounds

$3Mg(OH)_2$ + $Al_2(SO_4)_3$, $18H_2O$ = $3MgSO_4$ + $Al_2(OH)_6$ + $18H_2O$.

$Mg(OH)_2$ + CO_2 = $MgCO_3$ + H_2O.

$Mg(OH)_2$ + $CaH_2(CO_3)_2$ = $MgCO_3$ + $CaCO_3$ + H_2O.

$Mg(OH)_2$ + $2CO_2$ = $MgH_2(CO_3)_2$.

$Mg(OH)_2$ + $FeSO_4$, $7H_2O$ = $MgSO_4$ + $Fe(OH)_2$ + $7H_2O$.

$Mg(OH)_2$ + $MgH_2(CO_3)_2$ = $2MgCO_3$ + H_2O.

$Mg(OH)_2$ + $2NaHCO_3$ = $MgCO_3$ + Na_2CO_3 + H_2O.

$Mg(OH)_2$ + $2NaF$ = MgF_2 + $2NaOH$.

$3Mg(OH)_2$ + $2Na_2PO_4$, $12H_2O$ = $Mg_3(PO_4)_2$ + $6NaOH$ + $24H_2O$.

$Mg(OH)_2$ + H_2SO_4 = $MgSO_4$ + $2H_2O$.

$3MgCO_3$ + $Al_2(SO_4)_3$, $18H_2O$ = $3MgSO_4$ + $Al_2(OH)_6$ + $3CO_2$ + $15H_2O$.

$MgCO_3$ + $Ca(OH)_2$ = $Mg(OH)_2$ + $CaCO_3$.

$MgCO_3$ + CO_2 + H_2O = $MgH_2(CO_3)_2$.

$MgCO_3$ + $CuSO_4$, $5H_2O$ = $MgSO_4$ + $CuCO_3$ + $5H_2O$.

$MgCO_3$ + $FeSO_4$, $7H_2O$ = $MgSO_4$ + $Fe(OH)_2$ + $7H_2O$.

$MgCO_3 + 2HCl = MgCl_2 + CO_2 + H_2O$.

$MgCO_3 + 2NaF = MgF_2 + Na_2CO_3$.

$3MgCO_3 + 2Na_2PO_4, 12H_2O = Mg_3(PO_4)_2 + 3Na_2CO_3 + 24H_2O$.

$MgCO_3 + H_2SO_4 = MgSO_4 + CO_2 + H_2O$.

$3MgH_2(CO_3)_2 + Al_2(SO_4)_3, 18H_2O = 3MgSO_4 + Al_2(OH)_6 + 6CO_2 + 18H_2O$.

$MgH_2(CO_3)_2 + Ca(OH)_2 = MgCO_3 + CaCO_3 + 2H_2O$.

$MgH_2(CO_3)_2 + 2Ca(OH)_2 = Mg(OH)_2 + 2CaCO_3 + 2H_2O$.

$MgH_2(CO_3)_2 + CuSO_4, 5H_2O = MgSO_4 + CuCO_3 + 6H_2O$.

$MgH_2(CO_3)_2 + FeSO_4, 7H_2O = MgSO_4 + FeCO_3 + 8H_2O$.

$MgH_2(CO_3)_2 + 2HCl = MgCl_2 + 2CO_2 + 2H_2O$.

$MgH_2(CO_3)_2 + Mg(OH)_2 = 2MgCO_3 + H_2O$.

$MgH_2(CO_3)_2 + 2NaOH = MgCO_3 + Na_2CO_3 + H_2O$.

$MgH_2(CO_3)_2 + 4NaOH = Mg(OH_2)_2 + 2Na_2CO_3 + H_2O$.

$MgH_2(CO_3)_2 + 2NaF = MgF_2 + 2CO_2 + H_2O$.

$3MgH_2(CO_3)_2 + 2Na_2PO_4, 12H_2O = Mg_3(PO_4)_2 + 6NaHCO_3 + 15H_2O$.

$MgH_2(CO_3)_2 + H_2SO_4 = MgSO_4 + 2CO_2 + 2H_2O$.

$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$.

$MgCl_2 + 2NaOH = Mg(OH)_2 + 2NaCl$.

$MgCl_2 + Na_2CO_3 = MgCO_3 + 2NaCl$.

$MgCl_2 + 2NaF = MgF + [illegible]Cl$.

$MgCl_2 + 2Na_2PO_4, 12H_2O = Mg_3(PO_4)_2 + 6NaCl + 24H_2O$.

$MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$.

$MgSO_4 + 2NaOH = Mg(OH)_2 + Na_2SO_4$.

$MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$.

$MgSO_4 + 2NaF = MgF_2 + Na_2SO_4$.

$3MgSO_4 + 2Na_2PO_4, 12H_2O = Mg_3(PO_4)_2 + 3Na_2SO_4 + 24H_2O$.

Reactions of the Sodium Compounds

$6NaOH + Al_2(SO_4)_3, 18H_2O = 3NaSO_4 + Al_2(OH)_6 + H_2O$.

$2NaOH + CaH_2(CO_3)_2 = Na_2CO_3 + CaCO_3 + 2H_2O$.

$2NaOH + CaCl_2 = 2NaCl + Ca(OH)_2$.

$2NaOH + CaSO_4 = Na_2SO_4 + Ca(OH)_2$.

$2NaOH + CO_2 = Na_2CO_3 + H_2O$.

$2NaOH + CuSO_4, 5H_2O = Na_2SO_4 + Cu(OH)_2 + 5H_2O$.

$2NaOH + FeSO_4, 7H_2O = Na_2SO_4 + Fe(OH)_2 + 7H_2O$.

$2NaOH + 2HCl = 2NaCl + 2H_2O$.

$2NaOH + MgCO_3 = Na_2CO_3 + Mg(OH)_2$.

$4NaOH + MgH_2(CO_3)_2 = 2Na_2CO_3 + Mg(OH)_2 + 2H_2O$.

$4NaOH + MgCl_2 = 2NaCl + Mg(OH)_2$.

$4NaOH + MgSO_4 = Na_2SO_4 + Mg(OH)_2$.

$4NaOH + 2NaHCO_3 = 2Na_2CO_3 + H_2O$.

$4NaOH + H_2SO_4 = Na_2SO_4 + H_2O$.

$3Na_2CO_3 + Al_2(SO_4)_3, 18H_2O = 3Na_2SO_4 + Al_2(OH)_6 + 3CO_2 + 15H_2O.$

$Na_2CO_3 + Ca(OH)_2 = 2NaOH + CaCO_3.$

$Na_2CO_3 + CaCl_2 = 2NaCl + CaCO_3.$

$Na_2CO_3 + CaSO_4 = Na_2SO_4 + CaCO_3.$

$Na_2CO_3 + CO_2 + H_2O = 2NaHCO_3.$

$Na_2CO_3 + CuSO_4, 5H_2O = Na_2SO_4 + CuCO_3 + 5H_2O.$

$Na_2CO_3 + FeSO_4, 7H_2O = Na_2SO_4 + FeCO_3 + 7H_2O.$

$Na_2CO_3 + 2HCl = 2NaCl + CO_2 + H_2O.$

$Na_2CO_3 + MgCl_2 = 2NaCl + MgCO_3.$

$Na_2CO_3 + MgSO_4 = Na_2SO_4 + MgCO_3.$

$Na_2CO_3 + H_2SO_4 = Na_2SO_4 + CO_2 + H_2O.$

$6NaHCO_3 + Al_2(SO_4)_3, 18H_2O = 3Na_2SO_4 + 6CO_2 + 21H_2O.$

$NaHCO_3 + Ca(OH)_2 = NaOH + CaCO_3 + H_2O.$

$2NaHCO_3 + Ca(OH)_2 = Na_2CO_3 + CaCO_3 + 2H_2O.$

$NaHCO_3 + HCl = NaCl + CO_2 + H_2O.$

$2NaHCO_3 + H_2SO_4 = Na_2SO_4 + 2CO_2 + 2H_2O.$

$6NaF + Al_2(SO_4)_3, 18H_2O = 3Na_2SO_4 + 2AlF_3 + 18H_2O.$

$2NaF + Ca(OH)_2 = 2NaOH + CaF_2.$

$2NaF + CaCO_3 = Na_2CO_3 + CaF_2.$

$2NaF + CaH_2(CO_3)_2 = 2NaHCO_3 + CaF_2 + H_2O.$

$2NaF + CaCl_2 = 2NaCl + CaF_2.$

$2NaF + CaSO_4 = Na_2SO_4 + CaF_2.$

$2NaF + CuSO_4, 5H_2O = Na_2SO_4 + CuF_2 + 5H_2O.$

$2NaF + FeSO_4, 7H_2O = Na_2SO_4 + FeF_2 + 7H_2O.$

$2NaF + Mg(OH)_2 = 2NaOH + MgF_2.$

$2NaF + MgCO_3 = Na_2CO_3 + MgF_2.$

$2NaF + MgH_2(CO_3)_2 = 2NaHCO_3 + MgF_2.$

$2NaF + MgCl_2 = 2NaCl + MgF_2.$

$2NaF + MgSO_4 = Na_2SO_4 + MgF_2.$

$2Na_3PO_4, 12H_2O + Al_2(SO_4)_3, 18H_2O = 3Na_2SO_4 + 2AlPO_4 + 42H_2O.$

$2Na_3PO_4, 12H_2O + 3Ca(OH)_2 = 6NaOH + Ca_3(PO_4)_2 + 24H_2O.$

$2Na_3PO_4, 12H_2O + 2CaCO_3 = 3Na_2CO_3 + Ca_3(PO_4)_2 + 24H_2O.$

$2Na_3PO_4, 12H_2O + 3CaH_2(CO_3)_2 = 6NaHCO_3 + Ca_3(PO_4)_2 + 24H_2O.$

$2Na_3PO_4, 12H_2O + 3CaCl_2 = 6NaCl + Ca_3(PO_4)_2 + 24H_2O.$

$2Na_3PO_4, 12H_2O + 3CaSO_4 = 3Na_2SO_4 + Ca_3(PO_4)_2 + 24H_2O.$

$2Na_3PO_4, 12H_2O + CO_2 = 2Na_2HPO_4 + Na_2CO_3 + 23H_2O.$

$2Na_3PO_4, 12H_2O + 3CuSO_4, 5H_2O = 3Na_2SO_4 + Cu_3(PO_4)_2 + 39H_2O.$

$2Na_3PO_4, 12H_2O + 3FeSO_4, 7H_2O = 3Na_2SO_4 + Fe_3(PO_4)_2 + 45H_2O.$

$2Na_3PO_4, 12H_2O + 3Mg(OH)_2 = 6NaOH + Mg_3(PO_4)_2 + 27H_2O.$

$2Na_3PO_4, 12H_2O + 3MgCO_3 = 3Na_2CO_3 + Mg_3(PO_4)_2 + 24H_2O.$

$2Na_3PO_4, 12H_2O + 3MgH_2(CO_3)_2 = 6NaHCO_3 + Mg_3(PO_4)_2 + 24H_2O$.

$2Na_3PO_4, 12H_2O + 3MgCl_2 = 6NaCl + Mg_3(PO_4)_2 + 24H_2O$.

$2Na_3PO_4, 12H_2O + 3MgSO_4 = 3Na_2SO_4 + Mg_3(PO_4)_2 + 24H_2O$.

Reactions of Sulphuric Acid

$H_2SO_4 + Ba(OH)_2 = BaSO_4 + 2H_2O$.

$H_2SO_4 + BaCl_2, 2H_2O = BaSO_4 + 2HCl + 2H_2O$.

$H_2SO_4 + Ca(OH)_2 = CaSO_4 + 2H_2O$.

$H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$.

$H_2SO_4 + CaH_2(CO_3)_2 = CaSO_4 + 2CO_2 + 2H_2O$.

$H_2SO_4 + Mg(OH)_2 = MgSO_4 + 2H_2O$.

$H_2SO_4 + MgCO_3 = MgSO_4 + CO_2 + H_2O$.

$H_2SO_4 + MgH_2CO_3 = MgSO_4 + 2CO_2 + 2H_2O$.

$H_2SO_4 + 2NaOH = Na_2SO_4 + 2H_2O$.

$H_2SO_4 + Na_2CO_3 = Na_2SO_4 + CO_2 + H_2O$.

$H_2SO_4 + 2NaHCO_3 = Na_2SO_4 + 2CO_2 + 2H_2O$.

Use of Reactions

All of the preceding reactions may occur in the chemistry of water purification. In occasional instances other reactions will be found, but the preceding equations are those most generally used, and those occurring less frequently are too numerous to be included in this volume. Most of the questions commonly arising in water purification work may be answered by some one or more of the equations given, and a careful study of these reactions will shed much light on the rationale of various methods of water purification.

By taking any equation and substituting the chemical weights for the chemical formulas we obtain an arithmetical equation which can be proven to be correct arithmetically. and which is of value in enabling the operator to figure exactly how much weight of any two substances will be required to form a known weight of another substance.

For example, a water may have an alkalinity of 73 p.p.m. and the operator may desire to know how much hydrated lime will be required to reduce the alkalinity to 60 p.p.m., or, in other words, to eliminate 13 p.p.m. of alkalinity. The water is found by test to contain no free carbonic acid and likewise no monocarbonate alkalinity. It is not possible to learn from the alkalinity test only, how much of the alkalinity is composed of magnesium carbonate or sodium carbonate, but if the hardness is known to be in excess of the alkalinity, no sodium carbonate can be present. The operator therefore can safely assume that he can use enough lime to eliminate 13 p.p.m. of alkalinity, all of which may be considered as calcium alkalinity.

Under the reactions of the calcium compounds he finds $CaH_2(CO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$. Substituting the molecular or chemical weights for the formula,

he finds 162.1 + 74.1 = 2(100.1) + 2(18.0) or 162.1 + 74.1 = 200.2 + 36.0, or reduced still further, 236.2 = 236.2. The equation is thus proven mathematically and chemically correct. One part of alkalinity, however, does not represent 1.00 part of calcium bicarbonate, but 1 part of calcium monocarbonate in the form of calcium bicarbonate does equal one part of alkalinity, and under the calcium reactions he finds $CaCO_3 + CO_2 + H_2O = CaH_2(CO_3)_2$; and conversely, $CaH_2(CO_3)_2$ must equal $CaCO_3 + CO_2 + H_2O$, and he can therefore make his equation read $CaCO_3 + CO_2 + H_2O + Ca(OH)_2 = 2CaCO_3 + 2H_2O$, and substituting the molecular weights he has 100.1 + 44.0 + 18.0 + 74.1 = 2(100.1) + 2(18.0) or 100.1 + 44.0 + 18.0 + 74.1 = 200.2 + 36.0, or 236.2 = 236.2.

Now, as each part of alkalinity does represent one part of calcium monocarbonate, and as the preceding equation employs a formula wherein the calcium bicarbonate is reduced to its monocarbonate form, it is readily seen that 100.1 parts of alkalinity will require 74.1 parts of lime or calcium hydrate to reduce 162.1 parts of bicarbonate to the monocarbonate or insoluble state. Therefore, one part of alkalinity will require as much lime hydrate as 100.1 : 74.1 = 1.00 : X or 100.1 : 74.1 = 1.00 : .7402. Now, if 1 part of alkalinity requires .7402 part of calcium hydrate to eliminate, 13 parts will require .7402 × 13 = 9.62 parts of $Ca(OH)_2$ required. This is the result in p.p.m., while the operator usually wants to know how many grains per gallon will be required. To convert parts per million to grains per gallon one rule is to divide the parts per million by 17.1, and another rule is to multiply the parts per million by .0584. 9.62 ÷ 17.1 = .56 g.p.g. of calcium hydrate required.

9.62 × .0584 = .56 g.p.g. of calcium hydrate required. The operator would therefore use .56 g.p.g. of chemically pure hydrated lime to effect the removal of 13 p.p.m. of alkalinity in the above case.

Parts per Million

In order to understand the terms "p.p.m." and "g.p.g.," it may be necessary to explain that p.p.m. refers to the number of parts per million of one substance as compared with another. For instance, if a water is said to contain 73 p.p.m. of alkalinity we mean that one million parts of water by weight will contain 73 parts by weight of substances which are equivalent to 73 parts of calcium monocarbonate in their ability to produce alkalinity. Calcium monocarbonate forms the unit of measurement for alkalinity and is used as the base. Other alkaline compounds do not impart the same amount of alkalinity, weight for weight, that calcium monocarbonate does. The comparisons between the substances found in water or used in water purification processes will be found on pages 128-130, inclusive.

Grains per Gallon

A U. S. gallon contains 58,415 grains of water by weight. 73 p.p.m. = 4.26 g.p.g., and when we state that a water contains 4.26 g.p.g. of alkalinity we mean that each 58,415 parts of water by weight will contain 4.26 parts by weight of calcium monocarbonate or its equivalent in alkalinity producing substances. It will be obvious that if we take 58,415 milligrams of water and find 4.26 milligrams of alkalinity therein, we have 4.26 grains per gallon of alkalinity. 58,415 milligrams = 58.415 grams or 58.4 cubic centimeters of water approximately. An $\frac{N}{50}$ sulphuric acid volumetric solution is of such strength that each cubic centimeter of the acid solution neutralizes exactly 1 milligram of calcium monocarbonate. 58.4 c.c. of water is called the miniature U. S. gallon. Pipettes may be secured from any chemical supply house by special order which will discharge 58.4 c.c. of water, or a miniature U. S. gallon. If this quantity of water is titrated with $\frac{N}{50}$ sulphuric acid solution, each cubic centimeter of the acid solution required will indicate an alkalinity of one grain per gallon; and hence if the alkalinities be obtained from a miniature gallon the operator does not have to use the figures to convert p.p.m. into g.p.g. Any other chemical results which may be desired in grains per gallon can be obtained by employing a miniature U. S. gallon or a multiple of a U. S. gallon.

In our laboratory we have volumetric flasks which hold 584.1 c.c. of water. If this quantity of water is taken for analysis, each milligram of chemical separated therefrom corresponds to .1 g.p.g. We find this saves some calculations where the results are desired in g.p.g. The parts per million basis is more convenient in some ways than the grains per gallon, but as will be seen from the foregoing, it is a choice between two evils as to which standard shall be employed. We have found it advantageous to use both standards and to report results in both standards so as to meet the demands for either.

Chemical Factors

In order to save a large number of calculations we have prepared the following tables of chemical factors. These factors may be used in various ways. They all are based upon the formulas, weights and reactions given in the preceding pages. In order to use these tables understandingly a word or two of explanation is advisable. Chemical compounds may be decomposed into simpler substances. All chemical compounds are built up from simple or atomic substances. Thus, if we have a chemical compound we know that it is composed of certain simpler atomic substances or of combinations of these atomic substances. Thus, calcium monocarbonate is composed of CaO and carbonic acid, CO_2. We can prove

this in two ways. First, by taking calcium monocarbonate, limestone or marble, which are three different names for the same substance, and by heating the limestone or marble to a red heat for a sufficient period of time, we can drive off carbonic acid and have nothing left but calcium oxide, or CaO. We can weigh the quantity of limestone originally present, the quantity of carbonic acid given off, or the amount of calcium oxide left after burning. If the limestone be chemically pure we find that each pound or unit of the limestone will give off .4395 of carbonic acid, and there will be left .5604 of calcium oxide. Similarly, if we take .5604 of CaO and .4395 of CO_2 and unite them, we will have exactly one part of calcium monocarbonate. From the preceding we can readily calculate that one part of calcium oxide will form 1.7843 parts of calcium monocarbonate, while one part of carbon dioxide will form 2.275 parts of calcium monocarbonate, if we supply the carbonic acid or the calcium oxide, as the case may be.

Hence, if we have a given weight of calcium oxide or carbonic acid, we can calculate how much calcium monocarbonate may be formed from these known quantities; or if we have a given weight of calcium monocarbonate we can calculate with equal ease how much calcium oxide or carbonic acid it contains. All other chemical compounds follow this same rule. As the weight of the atomic substances varies, it will be readily seen that different substances must enter into combination in various relationships by weight. Also, in order to convert one substance into another, if we know the weight of one we may require to know the weight of the other to produce a given weight of a third, or a third and fourth. Some substances may be used to replace others, and it is desirable to know what weight will be required of one to equal a known weight of another. These tables are arranged upon the known substances being considered as unity, and the substances sought as a fraction of unity.

Factor Table

Aluminum Compounds

Known	Sought	Factor
Al	Al_2O_3	1.8856
Al	$Al_2(OH)_6$	2.8819
Al	$Al_2(SO_4)_3$	6.3169
Al	$Al_2(SO_4)_3$, 18 H_2O	12.2933
Al_2O_3	Al	.5303
Al_2O_3	O	.4696
Al_2O_3	$Al_2(OH)_6$	1.5283
Al_2O_3	$Al_2(SO)_4$	3.3501
Al_2O_3	$Al_2(SO_4)_3$, 18 H_2O	6.5203
$Al_2(OH)_6$	Al	.3469
$Al_2(OH)_6$	O	.6146
$Al_2(OH)_6$	H	.0384
$Al_2(OH)_6$	Al_2O_3	.6542
$Al_2(OH)_6$	H_2O	.3457
$Al_2(OH)_6$	$Al_2(SO_4)_3$	2.1919
$Al_2(OH)_6$	$Al_2(SO_4)_3$, 18 H_2O	4.2662
$Al_2(SO_4)_3$	Al	.1583
$Al_2(SO_4)_3$	Al_2O_3	.2985
$Al_2(SO_4)_3$	SO_3	.7014
$Al_2(SO_4)_3$	$Al_2(SO_4)_3$, 18 H_2O	1.9463
$Al_2(SO_4)_3$, 18 H_2O	Al	.0813
$Al_2(SO_4)_3$, 18 H_2O	Al_2O_3	.1533
$Al_2(SO_4)_3$, 18 H_2O	SO_3	.3604
$Al_2(SO_4)_3$, 18 H_2O	H_2O	.4862
$Al_2(SO_4)_3$, 18 H_2O	$Al_2(OH)_6$	.2344
$Al_2(SO_4)_3$, 18 H_2O	$Al_2(SO_4)_3$	.5138

Barium Compounds

Known	Sought	Factor
BaO	Ba	.8956
BaO	O	.1043
BaO	$Ba(OH)_2$	1.1173
BaO	$BaCO_3$	1.2868
BaO	$BaCl_2$, 2 H_2O	1.5925
BaO	$BaSO_4$	1.5218
$Ba(OH)_2$	BaO	.8949
$Ba(OH)_2$	H_2O	.1050
$Ba(OH)_2$, $8H_2O$	BaO	.4863
$Ba(OH)_2$, $8H_2O$	H_2O	.5136
$BaCO_3$	BaO	.7771
$BaCO_3$	CO_2	.2228
$BaCl_2$	Cl	.3403
$BaCl_2$	Ba	.6596
$BaCl_2$	$BaCl_2$, 2 H_2O	1.1728
$BaCl_2$	BaO	.7364
$BaCl_2$, $2H_2O$	Ba	.5624
$BaCl_2$, $2H_2O$	Cl	.2902
$BaCl_2$, $2H_2O$	$BaCl_2$	.8526
$BaCl_2$, $2H_2O$	H_2O	.1473
$BaCl_2$, $2H_2O$	BaO	.6279
$BaCl_2$, $2H_2O$	Cl	.2902
$BaCl_2$, $2H_2O$	HCl	.2984
$BaCl_2$, $2H_2O$	H_2O	.1473
$BaSO_4$	BaO	.6570
$BaSO_4$	SO_3	.3429

Calcium Compounds

Known	Sought	Factor
Ca	CaO	1.3390
O	CaO	3.5062
CaO	Ca	.7149
CaO	O	.2852
CaO	$Ca(OH)_2$	1.3208
CaO	$CaCO_3$	1.7843
CaO	$CaH_2(CO_3)_2$	2.8894
CaO	$CaCl_2$	1.9786
CaO	$Ca_3(PO_4)_2$	1.8556
CaO	$CaSO_4$	2.4271
$Ca(OH)_2$	CaO	.7571
$Ca(OH)_2$	H_2O	.2429
$CaCO_3$	CaO	.5604
$CaCO_3$	CO_2	.4395
$CaCO_3$	$CaH_2(CO_3)_2$	1.6194
$CaCO_3$	$CaCl_2$ (equiv.)	1.1088
$CaH_2(CO_3)_2$	CaO	.3461
$CaH_2(CO_3)_2$	CO_2	.5428
$CaH_2(CO_3)_2$	H_2O	.1110
$CaH_2(CO_3)_2$	$CaCO_3$	.6175
$CaCl_2$	Cl	.6387
$CaCl_2$	Ca	.3612

Calcium Compounds—Continued

Known	Sought	Factor
$CaCl_2$	CaO (equiv.)	.5054
$Ca_3(PO_4)_2$	CaO	.3877
$Ca_3(PO_4)_2$	P_2O_5	.6123
$CaSO_4$	CaO	.4120
$CaSO_4$	SO_3	.5880

Carbonic Acid Compounds

CO_2	CaO	1.2750
CO_2	$Ca(OH)_2$	1.6840
CO_2	$CaCO_3$	2.2750
CO_2	$CaH_2(CO_3)_2$	3.6840
CO_2	BaO	3.4863
CO_2	$Ba(OH)_2$	3.8954
CO_2	$BaCO_3$	4.4863
CO_2	MgO	.9172
CO_2	$Mg(OH)_2$	1.3263
CO_2	$MgCO_3$	1.7172
CO_2	$MgH_2(CO_3)_2$	3.3263
CO_2	Na_2O	1.4113
CO_2	NaOH	1.8204
CO_2	Na_2CO_3	2.4093
CO_2	NaH CO_3	3.8204

Copper Compounds

Cu	CuO	1.2515
CuO	Cu	.7990
CuO	O	.2010
CuO	$Cu(OH)_2$	1.2261
CuO	$CuCO_3$	1.5527
CuO	$CuSO_4$	2.0057
$Cu(OH)_2$	Cu	.6516
$Cu(OH)_2$	CuO	.8155
$Cu(OH)_2$	H_2O	.1844
$CuCO_3$	Cu	.5145
$CuCO_3$	CuO	.6440
$CuCO_3$	CO_2	.3559
$CuCl_2$, $2H_2O$	Cl	.4158
$CuCl_2$, $2H_2O$	Cu	.3730
$CuCl_2$, $2H_2O$	CuO	.4668
$CuCl_2$, $2H_2O$	H_2O	.2111
$CuSO_4$	Cu	.3983
$CuSO_4$	CuO	.4985
$CuSO_4$	SO_3	.5014
$CuSO_4$	$CuSO_4$, $5H_2O$	1.5637
$CuSO_4$, $5H_2O$	Cu	.2547
$CuSO_4$, $5H_2O$	CuO	.3188
$CuSO_4$, $5H_2O$	$CuSO_4$	.6395
$CuSO_4$, $5H_2O$	H_2O	.3604

Chlorine Compounds

Known	Sought	Factor
Cl	$CaCl_2$	1.5655
Cl	$BaCl_2$	2.9379
Cl	$BaCl_2$, $2H_2O$	3.4456
Cl	$CuCl_2$, $2H_2O$	2.4047
Cl	HCl	1.0282
Cl	$FeCl_2$	2.2115
Cl	$FeCl_2$, $4H_2O$	3.2270
Cl	$FeCl_3$	1.5256
Cl	$FeCl_3$, $6H_2O$	2.5411
Cl	$MgCl_2$	2.6871
Cl	NaCl	1.6502

Iron Compounds

Known	Sought	Factor
Fe	FeO	1.2862
Fe	Fe_2O_3	2.8483
Fe	$Fe(OH)_2$	1.6082
Fe	$Fe(OH)_3$	1.9123
Fe	$FeCO_3$	2.0733
Fe	$FeCl_2$	2.8050
Fe	$FeCl_2$, $4H_2O$	4.0930
Fe	$FeCl_3$	2.9025
Fe	$FeCl_3$, $6H_2O$	4.8345
	$FeSO_4$	2.7184
Fe	$FeSO_4$, $7H_2O$	4.9724
Fe	$Fe_2(SO_4)_3$	7.1565
FeO	Fe	.7775
FeO	O	.2225
FeO	Fe_2O_3	2.2225
FeO	$Fe(OH)_2$	1.2503
FeO	$Fe(OH)_3$	1.4867
FeO	$FeCO_3$	1.6119
FeO	$FeCl_2$	2.1808
FeO	$FeCl_2$, $4H_2O$	3.1821
FeO	$FeCl_3$	2.2566
FeO	$FeCl_3$, $6H_2O$	3.7586
FeO	$FeSO_4$	2.1134
FeO	$FeSO_4$, $7H_2O$	3.8659
FeO	$Fe_2(SO_4)_3$	5.5630
Fe_2O_3	Fe	.7021
Fe_2O_3	O	.2979
Fe_2O_3	FeO	.8998
Fe_2O_3	$Fe(OH)_2$	1.1251
Fe_2O_3	$Fe(OH)_3$	1.3379
Fe_2O_3	$FeCl_3$	2.0106
Fe_2O_3	$FeCl_3$, $6H_2O$	3.3823

Iron Compounds—Continued

Known	Sought	Factor
Fe_2O_3	$Fe_2(SO_4)_3$	2.5030
$Fe(OH)_2$	Fe	.6218
$Fe(OH)_2$	FeO	.7997
$Fe(OH)_2$	H_2O	.2002
$Fe(OH)_2$	$Fe(OH)_3$	1.1890
$Fe(OH)_2$	$FeCO_3$	1.2892
$Fe(OH)_2$	$FeSO_4$	1.6903
$Fe(OH)_2$	$FeSO_4$, $7H_2O$	3.0918
$Fe(OH)_3$	Fe	.5129
$Fe(OH)_3$	FeO	.6725
$Fe(OH)_3$	H_2O	.2526
$Fe(OH)_3$	$Fe(OH)_2$	.8409
$Fe(OH)_3$	Fe_2O_3	.7474
$Fe(OH)_3$	$Fe_2(SO_4)_3$	1.8708
$FeCO_3$	Fe	.4823
$FeCO_3$	FeO	.6203
$FeCO_3$	CO_2	.3796
$FeCO_3$	$Fe(OH)_2$	.7756
$FeCl_2$	Fe	.3565
$FeCl_2$	FeO	.4585
$FeCl_2$	Cl	.6434
$FeCl_2$	$FeCl_2$, $4H_2O$	1.4591
$FeCl_2$, $4H_2O$	Fe	.2443
$FeCl_2$, $4H_2O$	FeO	.3142
$FeCl_2$, $4H_2O$	Cl	.4410
$FeCl_2$, $4H_2O$	H_2O	.3146
$FeCl_2$, $4H_2O$	$Fe(OH)_2$	.3929
$FeCl_2$, $4H_2O$	$Fe(OH)_3$	.4672
$FeCl_2$, $4H_2O$	$FeCl_2$	.6853
$FeCl_3$	Fe	.3445
$FeCl_3$	Cl	.6554
$FeCl_3$	FeO	.4431
$FeCl_3$	Fe_2O_3	.4924
$FeCl_3$	$Fe(OH)_2$	.5540
$FeCl_3$	$Fe(OH)_3$	.6588
$FeCl_3$	$FeCl_3$, $6H_2O$	1.6656
$FeCl_3$, $6H_2O$	Fe	.2068
$FeCl_3$, $6H_2O$	Cl	.3935
$FeCl_3$, $6H_2O$	H_2O	.3996
$FeCl_3$, $6H_2O$	FeO	.2660
$FeCl_3$, $6H_2O$	Fe_2O_3	.2956
$FeCl_3$, $6H_2O$	$Fe(OH)_2$	.3326
$FeCl_3$, $6H_2O$	$Fe(OH)_3$	.3955
$FeCl_3$, $6H_2O$	$FeCl_3$	.6003
$FeSO_4$	Fe	.3678
$FeSO_4$	SO_3	.5268
$FeSO_4$	FeO	.4731
$FeSO_4$	Fe_2O_3	.5257
$FeSO_4$	$Fe(OH)_2$	.5916
$FeSO_4$	$Fe(OH)_3$	.7034
$FeSO_4$	$FeSO_4$, $7H_2O$	1.8291
$FeSO_4$	$Fe_2(SO_4)_3$	1.3165
$FeSO_4$	SO_3	.5268
$FeSO_4$, $7H_2O$	Fe	.2011

Iron Compounds—Continued

Known	Sought	Factor
$FeSO_4, 7H_2O$	FeO	.2586
$FeSO_4, 7H_2O$	Fe_2O_3	.2874
$FeSO_4, 7H_2O$	$Fe(OH)_2$	.3234
$FeSO_4, 7H_2O$	$Fe(OH)_3$	.3845
$FeSO_4, 7H_2O$	$FeSO_4$	.5566
$FeSO_4, 7H_2O$	SO_3	.2880
$FeSO_4, 7H_2O$	H_2O	.4533
$FeSO_4, 7H_2O$	$FeCO_3$	.4169
$FeSO_4, 7H_2O$	$Fe_2(SO_4)_3$	.7194
$Fe_2(SO_4)_3$	Fe	.2795
$Fe_2(SO_4)_3$	FeO	.3595
$Fe_2(SO_4)_3$	Fe_2O_3	.3995
$Fe_2(SO_4)_3$	$Fe(OH)_2$	.4495
$Fe_2(SO_4)_3$	$Fe(OH)_3$	.5345
$Fe_2(SO_4)_3$	$FeSO_4$	.7598
$Fe_2(SO_4)_3$	$FeSO_4, 7H_2O$	1.3898
$Fe_2(SO_4)_3$	SO_3	.6004

Magnesium Compounds

Mg	MgO	1.6568
Mg	$Mg(OH)_2$	2.3960
Mg	$MgCO_3$	3.4630
Mg	$MgH_2(CO_3)_2$	6.0082
Mg	$MgCl_2$	3.9105
Mg	$Mg_3(PO_4)_2$	3.5998
Mg	$Mg_2P_2O_7$	4.5714
Mg	$MgSO_4$	4.9433
MgO	Mg	.6035
MgO	O	.3964
MgO	$Mg(OH)_2$	1.4459
MgO	$MgCO_3$	2.0901
MgO	$MgH_2(CO_3)_2$	3.6263
MgO	$MgCl_2$	2.3602
MgO	$Mg_3(PO_4)_2$	2.1727
MgO	$Mg_2P_2O_7$	2.7591
MgO	$MgSO_4$	2.9836
$Mg(OH)_2$	Mg	.4174
$Mg(OH)_2$	MgO	.6915
$Mg(OH)_2$	H_2O	.3084
$Mg(OH)_2$	$Mg(CO)_3$	1.4455
$Mg(OH)_2$	$MgH_2(CO_3)_2$	2.5078
$Mg(OH)_2$	$MgCl_2$	1.6322
$Mg(OH)_2$	$Mg_3(PO_4)_2$	1.5026
$Mg(OH)_2$	$Mg_2(P_2O_7)$	1.9081
$Mg(OH)_2$	$MgSO_4$	2.0633
$MgCO_3$	Mg	.2887
$MgCO_3$	MgO	.4784
$MgCO_3$	CO_2	.5215
$MgH_2(CO_3)_2$	Mg	.1664
$MgH_2(CO_3)_2$	MgO	.2757
$MgH_2(CO_3)_2$	$MgCO_3$	.5763
$MgH_2(CO_3)_2$	H_2O	.1230
$MgH_2(CO_3)_2$	CO_2CO_2	.6012
$MgCl_2$	Mg	.2557

Magnesium Compounds — Continued

Known	Sought	Factor
$MgCl_2$	Cl	.7442
$MgCl_2$	MgO	.4236
$Mg_3(PO_4)_2$	Mg	2.7778
$Mg_3(PO_4)_2$	MgO	.4602
$Mg_3(PO_4)_2$	P_2O_5	.5397
$Mg_2P_2O_7$	Mg	.2187
$Mg_2P_2O_7$	MgO	.3624
$Mg_2P_2O_7$	P_2O_5	.6375
$MgSO_4$	Mg	.2022
$MgSO_4$	MgO	.3351
$MgSO_4$	SO_3	.6648

Sodium Compounds

Na	Na_2O	1.3470
Na	NaOH	1.7375
Na	Na_2CO_3	2.3015
Na	$Na_2CO_3, 10H_2O$	6.2060
Na	$NaHCO_3$	3.6464
Na	NaCl	2.5379
Na	NaF	1.8242
Na	Na_2HPO_4	3.0824
Na	$Na_2HPO_4, 12H_2O$	7.7678
Na	Na_3PO_4	2.3738
Na	$Na_3PO_4, 12H_2O$	5.4974
Na	Na_2SO_4	3.0837
Na	$Na_2SO_4, 10H_2O$	6.9882
Na_2O	Na	.7423
Na_2O	NaOH	1.2898
Na_2O	Na_2CO_3	1.7085
Na_2O	$Na_2CO_3, 10H_2O$	4.6070
Na_2O	$NaHCO_3$	2.7069
Na_2O	NaCl	1.8840
Na_2O	NaF	1.3542
Na_2O	Na_2HPO_4	2.2882
Na_2O	$Na_2HPO_4, 12H_2O$	5.7665
Na_2O	Na_3PO_4	1.7622
Na_2O	$Na_3PO_4, 12H_2O$	4.0799
Na_2O	Na_2SO_4	2.2892
Na_2O	$Na_2SO_4, 10H_2O$	5.1877
NaOH	Na	.5755
NaOH	Na_2O	.7752
NaOH	H_2O	.2247
NaOH	Na_2CO_3	1.3245
NaOH	$Na_2C_2O_3 10H_2O$	3.5717
NaOH	$NaHCO_3$	2.0986
NaOH	NaCl	1.4606

Sodium Compounds—Continued

Known	Sought	Factor
NaOH	NaF	1.0499
NaOH	Na_2HPO_4	1.7740
NaOH	Na_2HPO_4, $12H_2O$	4.4706
NaOH	Na_3PO_4	1.3662
NaOH	Na_3PO_4, $12H_2O$	3.1639
NaOH	Na_2SO_4	1.7747
NaOH	Na_2SO_4, $10H_2O$	4.0219
Na_2CO_3	Na	.4344
Na_2CO_3	Na_2O	.5862
Na_2CO_3	CO_2	.4147
Na_2CO_3	NaOH	.7549
Na_2CO_3	Na_2CO_3, $10H_2O$	2.6965
Na_2CO_3	$NaHCO_3$	1.5843
Na_2CO_3	NaCl	1.1027
Na_2CO_3	NaF	7.9264
Na_2CO_3	Na_2HPO_4	1.3393
Na_2CO_3	Na_2HPO_4, $12H_2O$	3.3751
Na_2CO_3	Na_3PO_4	1.0314
Na_2CO_3	Na_3PO_4, $12H_2O$	2.2500
Na_2CO_3	Na_2SO_4	1.3398
Na_2CO_3	Na_2SO_4, $10H_2O$	3.0363
Na_2CO_3, $10H_2O$	Na	.1611
Na_2CO_3, $10H_2O$	Na_2O	.2170
Na_2CO_3, $10H_2O$	CO_2	.1538
Na_2CO_3, $10H_2O$	H_2O	.6291
Na_2CO_3, $10H_2O$	NaOH	.2799
Na_2CO_3, $10H_2O$	Na_2CO_3	.3708
Na_2CO_3, $10H_2O$	$NaHCO_3$	.5875
Na_2CO_3, $10H_2O$	NaF	.2939
Na_2CO_3, $10H_2O$	Na_2HPO_4	.4966
Na_2CO_3, $10H_2O$	Na_2HPO_4, $12H_2O$	1.2516
Na_2CO_3, $10H_2O$	Na_3PO_4	.3825
Na_2CO_3, $10H_2O$	Na_3PO_4, $12H_2O$	.8858
Na_2CO_3, $10H_2O$	Na_2SO_4	.4968
Na_2CO_3, $10H_2O$	Na_2SO_4, $10H_2O$	1.1260
$NaHCO_3$	Na	.2472
$NaHCO_3$	Na_2O	.3694
$NaHCO_3$	CO_2	.5234
$NaHCO_3$	NaOH	.4765
$NaHCO_3$	Na_2CO_3	.6311
$NaHCO_3$	Na_2CO_3, $10H_2O$	1.7019
$NaHCO_3$	H_2O	.1071
$NaHCO_3$	Na_2SO_4	1.6913
$NaHCO_3$	Na_2SO_4, $10H_2O$	3.8329
NaCl	Na	.3940
NaCl	Cl	.6059

Sodium Compounds—Continued

Known	Sought	Factor
NaCl	Na_2O	.5307
NaCl	NaOH	.6846
NaF	Na	.5481
NaF	F	.4518
NaF	Na_2O	.7384
NaF	NaOH	.9524
Na_2HPO_4	Na	.3244
Na_2HPO_4	Na_2O	.4370
Na_2HPO_4	HPO_3	.5629
Na_2HPO_4	P_2O_5	.4996
Na_2HPO_4	Na_2HPO_4, $12H_2O$	2.5200
Na_2HPO_4, $12H_2O$	Na	.1287
Na_2HPO_4, $12H_2O$	Na_2O	.1734
Na_2HPO_4, $12H_2O$	HPO_3	.2234
Na_2HPO_4, $12H_2O$	P_2O_5	.1982
Na_2HPO_4, $12H_2O$	Na_2HPO_4	.3968
Na_2HPO_4, $12H_2O$	H_2O	.6031
Na_3PO_4	Na	.4212
Na_3PO_4	Na_2O	.5674
Na_3PO_4	P_2O_5	.4325
Na_3PO_4	Na_3PO_4, $12H_2O$	2.3158
Na_3PO_4, $12H_2O$	Na	.1819
Na_3PO_4, $12H_2O$	Na_2O	.2450
Na_3PO_4, $12H_2O$	P_2O_5	.1867
Na_3PO_4, $12H_2O$	Na_3PO_4	.4318
Na_3PO_4, $12H_2O$	H_2O	.5681
Na_2SO_4	Na	.3242
Na_2SO_4	Na_2O	.4368
Na_2SO_4	NaOH	.5634
Na_2SO_4	Na_2CO_3	.7463
Na_2SO_4	Na_2CO_3, $10H_2O$	2.0125
Na_2SO_4	Na_2SO_4, $10H_2O$	2.2661
Na_2SO_4	SO_3	.5631
Na_2SO_4, $10H_2O$	Na	.1430
Na_2SO_4, $10H_2O$	Na_2O	.1927
Na_2SO_4, $10H_2O$	NaOH	.2486
Na_2SO_4, $10H_2O$	Na_2CO_3	.3293
Na_2SO_4, $10H_2O$	Na_2CO_3, $10H_2O$	.8880
Na_2SO_4, $10H_2O$	Na_2SO_4	.4412
Na_2SO_4, $10H_2O$	H_2O	.5587
Na_2SO_4, $10H_2O$	SO_3	.2485

Sulphuric Acid Compounds

SO_3	$Al_2(SO_4)_3$	1.4255
SO_3	$Al_2(SO_4)_3$, $18H_2O$	2.7745
SO_3	$BaSO_4$	2.9160
SO_3	$CaSO_4$	1.7007
SO_3	$CuSO_4$	1.9940
SO_3	$CuSO_4$, $5H_2O$	3.1184

Sulphuric Acid Compounds
Continued

Known	Sought	Factor
SO_3	$FeSO_4$	1.8980
SO_3	$FeSO_4$, 7 H_2O	3.4718
SO_3	$MgSO_4$	1.5041
SO_3	Na_2SO_4	1.7756
SO_3	Na_2SO_4, $10H_2O$	4.0239
SO_3	H_2SO_4	1.2248
H_2SO_4	SO_3	.8164
H_2SO_4	H_2O	.1835

Alkalinity Equivalents

The different substances which produce alkalinity in water are of different values, weight for weight, in their power to produce alkalinity. Thus the same quantity by weight of calcium monocarbonate, magnesium monocarbonate and sodium monocarbonate will not impart the same amount of alkalinity to the same quantity of water. In order to measure the amount of alkalinity in any given sample of water, it became necessary to have some standard unit of measurement.

The unit of measurement which was chosen was calcium monocarbonate, $CaCO_3$. The reason for choosing this substance as the unit was found in its molecular weight, which at the time was supposed to be 100.00. At the time these tables were prepared, the molecular weight of calcium monocarbonate had been slightly changed and was considered to be 100.1 and the tables are computed on this value.

Under this assumption, if a given sample of water contained 1.001 milligrams of calcium monocarbonate in 1,000,000 parts of water, it would require exactly one cubic centimeter of $\frac{N}{50}$ Sulphuric Acid Solution to effect its neutralization, and it would be said to have an alkalinity of one part per million. If the same quantity of calcium monocarbonate were found present in 58,415 milligrams of water, it would require one cubic centimeter of $\frac{N}{50}$ Sulphuric Acid Solution to effect its neutralization and the sample would be said to possess an alkalinity of one grain per gallon. If the alkalinity in both samples was composed of magnesium monocarbonate and required the same volume of $\frac{N}{50}$ Sulphuric Acid Solution to neutralize, the alkalinity of the samples would be the same as in the preceding case, but instead of there being 1.001 milligrams of $MgCO_3$ present, there would only be .8427 milligram of $MgCO_3$ in the samples. In other words, .8427 milligram of $MgCO_3$ is equal to 1.001 milligrams of $CaCO_3$ in its power to produce alkalinity. It requires 1.06 milligrams of sodium monocarbonate to produce the same alkalinity as .8427 milligram of $MgCO_3$ or 1.001 milligrams of $CaCO_3$.

The following tables show the values of the various chemical compounds which may be found in water or used in water purification processes, in producing alkalinity, as compared against the unity value of the substance represented

by the formula at the head of each table. Thus one part of the substance heading these tables will have the same alkalinity value as is indicated in weight of the other chemical compounds forming the body of the tables.

Alkalinity Equivalents

CaO

Substance	Factor
$Al_2(OH)_6$	.6072
BaO	2.7344
$Ba(OH)_2$	3.0552
$Ca(OH)_2$	1.3208
$CaCO_3$	1.7843
$CaH_2(CO_3)_2$	2.8894
MgO	.7194
$Mg(OH)_2$	1.0402
$MgCO_3$	1.5037
$MgH_2(CO_3)_2$	2.6089
Na_2O	1.1069
NaOH	1.4278
Na_2CO_3	1.8912
$NaHCO_3$	2.9864

$Ca(OH)_2$

$Al_2(OH)_6$	.7026
BaO	2.0701
$Ba(OH)_2$	2.3130
CaO	.7571
$CaCO_3$	1.3508
$CaH_2(CO_3)_2$	2.1875
MgO	.5446
$Mg(OH)_2$	.7875
$MgCO_3$	1.1384
$MgH_2(CO_3)_2$	1.9751
Na_2O	.8380
NaOH	1.0809
Na_2CO_3	1.4318
$NaHCO_3$	2.2685

(Standard) $CaCO_3$

$Al_2(OH)_6$	.5201
BaO	1.5324
$Ba(OH)_2$	1.7122
CaO	.5604
$Ca(OH)_2$	.7402
$CaH_2(CO_3)_2$	1.6193
MgO	.4031
$Mg(OH)_2$	.5830
$MgCO_3$	.8427
$MgH_2(CO_3)_2$	1.4621
Na_2O	.6203
NaOH	.8001
Na_2CO_3	1.0599
$NaHCO_3$	1.6793

$CaH_2(CO_3)_2$

Substance	Factor
$Al_2(OH)_6$	.3212
BaO	.9463
$Ba(OH)_2$	1.0573
CaO	.3460
$Ca(OH)_2$	.4571
$CaCO_3$	.6175
MgO	.2489
$Mg(OH)_2$	.3600
$MgCO_3$	.5204
$MgH_2(CO_3)_2$	.9028
Na_2O	.3830
NaOH	.4941
Na_2CO_3	.6539
$NaHCO_3$	1.0370

MgO

$Al_2(OH)_6$	1.2900
BaO	3.8007
$Ba(OH)_2$	4.2466
CaO	1.3899
$Ca(OH)_2$	1.8359
$CaCO_3$	2.4801
$CaH_2(CO_3)_2$	4.0163
$Mg(OH)_2$	1.4459
$MgCO_3$	2.0901
$MgH_2(CO_3)_2$	3.6263
Na_2O	1.5386
NaOH	1.9846
Na_2CO_3	2.6288
$NaHCO_3$	4.1650

$Mg(OH)_2$

$Al_2(OH)_6$	.8921
BaO	2.6285
$Ba(OH)_2$	2.9369
CaO	.9612
$Ca(OH)_2$	1.2697
$CaCO_3$	1.7152
$CaH_2(CO_3)_2$	2.7775
MgO	.6915
$MgCO_3$	1.4455
$MgH_2(CO_3)_2$	2.5078
Na_2O	1.0640
NaOH	1.3725
Na_2CO_3	1.8180
$NaHCO_3$	2.8803

Alkalinity Equivalents—Continued

$MgCO_3$

Substance	Factor
$Al_2(OH)_6$	.6171
BaO	1.8183
$Ba(OH)_2$	2.0317
CaO	.6650
$Ca(OH)_2$	.8783
$CaCO_3$	1.1865
$CaH_2(CO_3)_2$	1.9215
MgO	.4784
$Mg(OH)_2$	.6917
$MgH_2(CO_3)_2$	1.7349
Na_2O	.7361
NaOH	.9495
Na_2CO_3	1.2577
$NaHCO_3$	1.9926

$MgH_2(CO_3)_2$

Substance	Factor
$Al_2(OH)_6$	.3557
BaO	1.0481
$Ba(OH)_2$	1.1710
CaO	.3833
$Ca(OH)_2$	.5062
$CaCO_3$	.6839
$CaH_2(CO_3)_2$	1.1075
MgO	.2757
$Mg(OH)_2$	.3987
$MgCO_3$	.5763
Na_2O	.4242
NaOH	.5472
Na_2CO_3	.7249
$NaHCO_3$	1.1485

Na_2O

Substance	Factor
BaO	2.4702
$Ba(OH)_2$	2.7600
CaO	.9033
$Ca(OH)_2$	1.1932
$CaCO_3$	1.6119
$CaH_2(CO_3)_2$	2.6103
MgO	.6499
$Mg(OH)_2$	.9397
$MgCO_3$	1.3584
$MgH_2(CO_3)_2$	2.3568
NaOH	.6449
Na_2CO_3	1.7085
$Na_2CO_3 \cdot 10H_2O$	4.6070
$NaHCO_3$	1.3534

NaOH

Substance	Factor
BaO	1.9151
$Ba(OH)_2$	2.1398
CaO	.7003
$Ca(OH)_2$	.9250
$CaCO_3$	1.2496
$CaH_2(CO_3)_2$	2.0237
MgO	.5038
$Mg(OH)_2$	.7285
$MgCO_3$	1.0351
$MgH_2(CO_3)_2$	1.8272
Na_2O	.7752
Na_2CO_3	1.3245
$Na_2CO_3 \cdot 10H_2O$	3.5717
$NaHCO_3$	2.0986

Na_2CO_3

Substance	Factor
BaO	1.4458
$Ba(OH)_2$	1.6154
CaO	.5287
$Ca(OH)_2$	.6983
$CaCO_3$	.9434
$CaH_2(CO_3)_2$	1.5278
MgO	.3803
$Mg(OH)_2$	.5500
$MgCO_3$	.7950
$MgH_2(CO_3)_2$	1.3794
Na_2O	.5852
NaOH	.7549
$Na_2CO_3 \cdot 10H_2O$	2.6965
$NaHCO_3$	1.5843

Hardness Equivalents

As in the Alkalinity Equivalent tables, the hardness imparted by the various hardening compounds is not the same. In the following tables the hardening values are compared exactly as in the Alkalinity Equivalent tables. Thus one part of the compound heading each table will produce as much hardness as is indicated by the factors given opposite the substances forming the body of the table. The unit of measurement is the same as the alkalinity, viz: $CaCO_3$.

Hardness Equivalents

$Al_2(SO_4)_3,18H_2O$

Substance	Factor
$Al_2(OH)_6$	.2344
$Al_2(SO_4)_3$	.5137
BaO	.6905
$Ba(OH)_2$	.7716
CaO	.2525
$Ca(OH)_2$	.3335
$CaCO_3$	.4506
$CaH_2(CO_3)_2$	.7297
$CaCl_2$	.4997
$CaSO_4$	.6129
CO_2	.1980
$CuSO_4$	.7187
$CuSO_4, 5H_2O$	1.1239
$FeSO_4$	.6841
$FeSO_4, 7H_2O$	1.2513
HCl	.1640
MgO	.1816
$Mg(OH)_2$	.2627
$MgCO_3$	.3797
$MgH_2(CO_3)_2$	.6589
$MgCl_2$	.4288
$MgSO_4$	.5421
SO_3	.3604
H_2SO_4	.4415

$Ca(OH)_2$

Substance	Factor
$Al_2(OH)_6$	.7026
$Al_2(SO_4)_3$	1.5401
$Al_2(SO_4)_3, 18H_2$	2.9976
BaO	2.0701
$Ba(OH)_2$	2.3130
CaO	.7571
$CaCO_3$	1.3508
$CaH_2(CO_3)_2$	2.1875
$CaCl_2$	1.4979
$CaSO_4$	1.8375
CO_2	.5938
$CuSO_4$	2.1546
$CuSO_4, 5H_2O$	3.3692
$FeSO_4$	2.0507
$FeSO_4, 7H_2O$	3.7511
HCl	.9838
MgO	.5446
$Mg(OH)_2$	.7875
$MgCO_3$	1.1384
$MgH_2(CO_3)_2$	1.9751
$MgCl_2$	1.2855
$MgSO_4$	1.6251
SO_3	1.0804
H_2SO_4	1.3233

CaO

$Al_2(OH)_6$	.6072
$Al_2(SO_4)_3$	2.0343
$Al_2(SO_4)_3, 18H_2O$	3.9594
BaO	2.7344
$Ba(OH)_2$	3.0552
$Ca(OH)_2$	1.3208
CaCO	1.7843
$CaH_2(CO_3)_2$	2.8894
$CaCl_2$	1.9786
$CaSO_4$	2.427
CO_2	.7843
$CuSO_4$	2.8456
$CuSO_4, 5H_2O$	4.4502
$FeSO_4$	2.7087
$FeSO_4, 7H_2O$	4.9547
HCl	1.2994
MgO	.7194
$Mg(OH)_2$	1.0402
$MgCO_3$	1.5037
$MgH_2(CO_3)_2$	2.6089
$MgCl_2$	1.6980
$MgSO_4$	2.1465
SO_3	1.4270
H_2SO_4	1.7479

$CaCO_3$

$Al_2(OH)_6$	.5201
$Al_2(SO_4)_3$	1.1401
$Al_2(SO_4)_3, 18H_2O$	2.2190
BaO	1.5324
$Ba(OH)_2$	1.7122
CaO	.5604
$Ca(OH)_2$	.7402
$CaH_2(CO_3)_2$	1.6193
$CaCl_2$	1.1088
$CaSO_4$	1.3602
CO_2	.4395
$CuSO_4$	1.5950
$CuSO_4, 5H_2O$	2.4941
$FeSO_4$	1.5180
$FeSO_4, 7H_2O$	2.7768
HCl	.7282
MgO	.4031
$Mg(OH)_2$	.5830
$MgCO_3$	.8427
$MgH_2(CO_3)_2$	1.4621
$MgCl_2$	.9516
$MgSO_4$	1.2029
SO_3	.7998
H_2SO_4	.9796

Hardness Equivalents—Continued

$CaH_2(CO_3)_2$

Substance	Factor
$Al_2(OH)_6$	.3212
$Al_2(SO_4)_3$	.7040
$Al_2(SO_4)_3$, $18H_2O$	1.3703
BaO	.9463
$Ba(OH)_2$	1.0573
CaO	.3460
$Ca(OH)_2$	.4571
$CaCO_3$	.6175
$CaCl_2$	.6847
$CaSO_4$	.8399
CO_2	.2714
$CuSO_4$	.9849
$CuSO_4$, $5H_2O$	1.5401
$FeSO_4$	.9374
$FeSO_4$, $7H_2O$	1.7147
HCl	.4497
MgO	.2489
$Mg(OH)_2$	.3600
$MgCO_3$	.5204
$MgH_2(CO_3)_2$	.9028
$MgCl_2$	.5876
$MgSO_4$	.7428
SO_2	.4938
H_2SO_4	.6048

$CaSO_4$

Substance	Factor
$Al_2(OH)_6$	.3823
$Al_2(SO_4)_3$	.8381
$Al_2(SO_4)_3$, $18H_2O$	1.6311
BaO	1.1266
$Ba(OH)_2$	1.2588
CaO	.4120
$Ca(OH)_2$	.5442
$CaCO_3$	.7351
$CaH_2(CO_3)_2$	1.1905
$CaCl_2$	.8152
CO_2	.3231
$CuSO_4$	1.1725
$CuSO_4$, $5H_2O$	1.8335
$FeSO_4$	1.1160
$FeSO_4$, $7H_2O$	2.0414
HCl	.5354
MgO	.2964
$Mg(OH)_2$	.4286
$MgCO_3$	.6195
$MgH_2(CO_3)_2$	1.0749
$MgCl_2$	.6996
$MgSO_4$	.8844
SO_2	.5879
H_2SO_4	.7201

$CaCl_2$

Substance	Factor
$Al_2(OH)_6$	.4690
$Al_2(SO_4)_3$	1.0281
$Al_2(SO_4)_3$, $18H_2O$	2.0011
BaO	1.3819
$Ba(OH)_2$	1.5441
CaO	.5054
$Ca(OH)_2$	.6675
$CaCO_3$	.9018
$CaH_2(CO_3)_2$	1.4603
$CaSO_4$	1.2266
CO_2	.3963
$CuSO_4$	1.4383
$CuSO_4$, $5H_2O$	2.2491
$FeSO_4$	1.3690
$FeSO_4$, $7H_2O$	2.5041
HCl	.6567
MgO	.3636
$Mg(OH)_2$	.5257
$MgCO_3$	.7600
$MgH_2(CO_3)_2$	1.3185
$MgCl_2$	.8581
$MgSO_4$	1.0848
SO_2	.7212
H_2SO_4	.8834

CO_2

Substance	Factor
$Al_2(OH)_6$	1.1833
$Al_2(SO_4)_3$	2.5937
$Al_2(SO_4)_3$, $18H_2O$	5.0483
BaO	3.4863
$Ba(OH)_2$	3.8954
CaO	1.2750
$Ca(OH)_2$	1.6840
$CaCO_3$	2.2750
$CaH_2(CO_3)_2$	3.6840
$CaCl_2$	2.5227
$CaSO_4$	3.0945
$CuSO_4$	3.6286
$CuSO_4$, $5H_2O$	5.6740
$FeSO_4$	3.4536
$FeSO_4$, $7H_2O$	6.3172
HCl	1.6568
MgO	.9172
$Mg(OH)_2$	1.3263
$MgCO_3$	1.9172
$MgH_2(CO_3)_2$	3.3263
$MgCl_2$	2.1650
$MgBO_4$	2.7368
SO_2	1.8195
H_2SO_4	2.2286

Hardness Equivalents—Continued

$CuSO_4$, $5H_2O$

Substance	Factor
$Al_2(OH)_6$	.2085
$Al_2(SO_4)_3$	.4571
$Al_2(SO_4)_3$, $18H_2O$	.8897
BaO	.6144
$Ba(OH)_2$	.6865
CaO	.2247
$Ca(OH)_2$	.2968
$CaCO_3$	.4009
$CaH_2(CO_3)_2$	.6492
$CaCl_2$	.4446
$CaSO_4$	.5453
CO_2	.1762
$CuSO_4$	.6395
FeSO	.6086
$FeSO_4$, $7H_2O$	1.1133
HCl	.2919
MgO	.1616
$Mg(OH)_2$	.2337
$MgCO_3$	.3379
$MgH_2(CO_3)_2$	.5862
$MgCl_2$	.3815
$MgSO_4$	.4823
SO_3	.3206
H_2SO_4	.3927

MgO

Substance	Factor
$Al_2(OH)_6$	1.2900
$Al_2(SO_4)_3$	2.8277
$Al_2(SO_4)_3$, $18H_2O$	5.5036
BaO	3.8007
$Ba(OH)_2$	4.2466
CaO	1.3899
$Ca(OH)_2$	1.8359
$CaCO_3$	2.4801
$CaH_2(CO_3)_2$	4.0163
$CaCl_2$	2.7502
$CaSO_4$	3.3736
CO_2	1.0901
$CuSO_4$	3.9558
$CuSO_4$, $5H_2O$	6.1858
$FeSO_4$	3.7651
$FeSO_4$, $7H_2O$	6.8870
HCl	1.8062
$Mg(OH)_2$	1.4459
$MgCO_3$	2.0901
$MgH_2(CO_3)_2$	3.6263
$MgCl_2$	2.3602
$MgSO_4$	2.9836
SO_3	1.9838
H_2SO_4	2.4296

$FeSO_4$, $7H_2O$

Substance	Factor
$Al_2(OH)_6$	.1873
$Al_2(SO_4)_3$	.4105
$Al_2(SO_4)_3$, $18H_2O$	.7991
BaO	.5518
$Ba(OH)_2$	.6166
CaO	.2018
$Ca(OH)_2$	.2665
$CaCO_3$	.3601
$CaH_2(CO_3)_2$	.5831
$CaCl_2$	.3993
$CaSO_4$	.4898
CO_2	.1582
$CuSO_4$	.5743
$CuSO_4$, $5H_2O$	.8981
$FeSO_4$	.5466
HCl	.2622
MgO	.1452
$Mg(OH)_2$	.2099
$MgCO_3$	.3034
$MgH_2(CO_3)_2$	.5252
$MgCl_2$	.3427
$MgSO_4$	.4332
SO_3	.2880
H_2SO_4	.3527

$Mg(OH)_2$

Substance	Factor
$Al_2(OH)_6$	.8921
$Al_2(SO_4)_3$	1.9555
$Al_2(SO_4)_3$, $18H_2O$	3.8061
BaO	2.6285
$Ba(OH)_2$	2.9369
CaO	.9612
$Ca(OH)_2$	1.2697
$CaCO_3$	1.7152
$CaH_2(CO_3)_2$	2.7775
$CaCl_2$	1.9019
$CaSO_4$	2.3331
CO_2	.7539
$CuSO_4$	2.7357
$CuSO_4$, $5H_2O$	4.2779
$FeSO_4$	2.6038
$FeSO_4$, $7H_2O$	4.7628
HCl	1.2491
MgO	6915
$MgCO_3$	1.4455
$MgH_2(CO_3)_2$	2.5078
$MgCl_2$	1.6322
$MgSO_4$	2.0633
SO_3	1.3718
H_2SO_4	1.6802

Hardness Equivalents—Concluded

$MgCO_3$

Substance	Factor
$Al_2(OH)_6$	.6171
$Al_2(SO_4)_3$	1.3528
$Al_2(SO_4)_3$, $18H_2O$	2.6330
BaO	1.8183
$Ba(OH)_2$	2.0317
CaO	.6650
$Ca(OH)_2$	.8783
$CaCO_3$	1.1865
$CaH_2(CO_3)_2$	1.9215
$CaCl_2$	1.3157
$CaSO_4$	1.6140
CO_2	.5215
$CuSO_4$	1.8926
$CuSO_4$, $5H_2O$	2.9594
$FeSO_4$	1.8013
$FeSO_4$, $7H_2O$	3.2949
HCl	.8641
MgO	.4784
$Mg(OH)_2$	.6917
$MgH_2(CO_3)_2$	1.7349
$MgCl_2$	1.1292
$MgSO_4$	1.4274
SO_3	.9490
H_2SO_4	1.1623

$MgCl_2$

Substance	Factor
$Al_2(OH)_6$	.5465
$Al_2(SO_4)_3$	1.1980
$Al_2(SO_4)_3$, $18H_2O$	2.3317
BaO	1.6103
$Ba(OH)_2$	1.7992
CaO	.5889
$Ca(OH)_2$	.7778
$CaCO_3$	1.0508
$CaH_2(CO_3)_2$	1.7016
$CaCl_2$	1.1652
$CaSO_4$	1.4293
CO_2	.4618
$CuSO_4$	1.6760
$CuSO_4$, $5H_2O$	2.6208
$FeSO_4$	1.5952
$FeSO_4$, $7H_2O$	2.9179
HCl	.7652
MgO	.4236
$Mg(OH)_2$	.6126
$MgCO_3$	.8855
$MgH_2(CO_3)_2$	1.5364
$MgSO_4$	1.2641
SO_3	.8404
H_2SO_4	1.0293

$MgH_2(CO_3)_2$

Substance	Factor
$Al_2(OH)_6$	.3557
$Al_2(SO_4)_3$	.7797
$Al_2(SO_4)_3$, $18H_2O$	1.5176
BaO	1.0481
$Ba(OH)_2$	1.1710
CaO	.3833
$Ca(OH)_2$	.5062
$CaCO_3$	.6839
$CaH_2(CO_3)_2$	1.1075
$CaCl_2$	.7584
$CaSO_4$	.9303
CO_2	.3006
$CuSO_4$	1.0908
$CuSO_4$, $5H_2O$	1.7057
$FeSO_4$	1.0382
$FeSO_4$, $7H_2O$	1.8991
HCl	.4980
MgO	.2757
$Mg(OH)_2$	.3987
$MgCO_3$	.5763
$MgCl_2$	.6508
$MgSO_4$	.8227
SO_3	.5470
H_2SO_4	.6699

$MgSO_4$

Substance	Factor
$Al_2(OH)_6$	.4323
$Al_2(SO_4)_3$	.9477
$Al_2(SO_4)_3$, $18H_2O$	1.8445
BaO	1.2738
$Ba(OH)_2$	1.4233
CaO	.4658
$Ca(OH)_2$	.6153
$CaCO_3$	.8312
$CaH_2(CO_3)_2$	1.3461
$CaCl_2$	.9217
$CaSO_4$	1.1307
CO_2	.3653
$CuSO_4$	1.3258
$CuSO_4$, $5H_2O$	2.0732
$FeSO_4$	1.2619
$FeSO_4$, $7H_2O$	2.3082
HCl	6053
MgO	.3351
$Mg(OH)_2$	.4846
$MgCO_3$	.7005
$MgH_2(CO_3)_2$	1.2154
$MgCl_2$	.7910
SO_3	.6648
H_2SO_4	.8143

Incompatible Equivalents

Two substances which are chemically incompatible cannot remain in the same solution. In the following tables the substance heading the table is chemically incompatible to each substance in the table. These tables may, therefore, be used as Chemical Treatment Tables. One part of the substance heading each table will either remove, displace, decompose, neutralize or precipitate any one of the substances in the table in the ratio of the factors given. Commercial chemicals are neither chemically pure or wholly utilizable and this should be allowed for, as the tables are based on chemical purity and complete availability. It must also be evident that if exact equivalents be used, all of the incompatibles will be eliminated, and thus the substance treated, as well as that used to treat, will be removed and neither will remain in solution. In the table headed Iron Sulphate we find one part of this will remove or neutralize 0.2018 of Calcium Oxide, 0.2665 of Calcium Hydrate, or 0.3817 of Sodium Monocarbonate, and, vice versa, these amounts of alkali will remove or precipitate one part of Iron Sulphate. The other tables are used in the same way.

$Al_2(SO_4)_3$, $18H_2O$

Substance	Factor
BaO	.6907
$Ba(OH)_2$	.7716
CaO	.2525
$Ca(OH)_2$	.3335
$CaCO_3$	.4504
$CaH_2(CO_3)_2$	.7297
$Mg(OH)_2$	.2627
$MgCO_3$	.3797
$MgH_2(CO_3)_2$	.6589
Na_2O	.2795
NaOH	.3606
Na_2CO_3	.4776
$NaHCO_3$	.7567
Na_2CO_3, 10 H_2O	1.2880
NaF	.3786

BaO

$Al_2(SO_4)_3$, $18H_2O$	1.4480
$CaCO_3$	.6525
$CaH_2(CO_3)_2$	1.0567
$CaSO_4$	.8876
CO_2	.2868
$FeSO_4$, $7H_2O$	1.8116
$MgCO_3$	.5499
$MgH_2(CO_3)_2$	.9541
$MgSO_4$	.7850
Na_2CO_3	.6916
$NaHCO_3$	1.0958
Na_2SO_4	.9267
SO_3	.5219
H_2SO_4	.6392

CaO

$Al_2(SO_4)_3$,	2.0343
$Al_2(SO_4)_3$, $18H_2O$	3.9594
$CaH_2(CO_3)_2$	2.8894
CO_2	.7843
$CuSO_4$	2.8456
$CuSO_4$, $5H_2O$	4.4502
HCl	1.2994
$FeSO_4$	2.7087
$FeSO_4$, $7H_2O$	4.9547
$MgCO_3$	.665
$MgH_2(CO_3)_2$	.7666
$MgCl_2$	1.698
$MgSO_4$	2.1465
SO_3	1.427
H_2SO_4	1.7479

Incompatible Equivalents—Continued

$Ca(OH)_2$

Substance	Factor
$Al_2(SO_4)_3$	1.5401
$Al_2(SO_4)_3$, $18H_2O$	2.9976
$CaH_2(CO_3)_2$	2.1875
CO_2	.5938
$CuSO_4$	2.1546
$CuSO_4$, $5H_2O$	3.3692
HCl	.9838
$FeSO_4$	2.0507
$FeSO_4$, $7H_2O$	3.7511
$MgCO_3$	1.1384
$MgH_2(CO_3)_2$	.9875
$MgCl_2$	1.2855
$MgSO_4$	1.6251
SO_2	1.0804
H_2SO_4	1.3233

$CaCO_3$

$Al_2(SO_4)_3$	1.1401
$Al_2(SO_4)_3$, $18H_2O$	2.2190
$CuSO_4$	1.5950
$CuSO_4$, $5H_2O$	2.4941
HCl	.7282
$FeSO_4$	1.5180
$FeSO_4$, $7H_2O$	2.7768
SO_2	.7998
H_2SO_4	.9796

$CaH_2(CO_3)_2$

$Al_2(SO_4)_3$	.7040
$Al_2(SO_4)_3$, $18H_2O$	1.3703
$CuSO_4$	.9849
$CuSO_4$, $5H_2O$	1.5401
HCl	.4497
SO_2	.4938
H_2SO_4	.6048

$CaCl_2$

BaO	1.3819
$Ba(OH)_2$	1.5441
Na_2O	.5594
NaOH	.7216
Na_2CO_3	.9558

$CaSO_4$

Substance	Factor
BaO	1.1266
$Ba(OH)_2$	1.2588
Na_2O	.4560
NaOH	.5882
Na_2CO_3	.7792

Free CO_2

BaO	3.4863
$Ba(OH)_2$	3.8954
CaO	1.2750
$Ca(OH)_2$	1.6840
$CaCO_3$	2.2750
MgO	.9172
$Mg(OH)_2$	1.3263
$MgCO_3$	1.9172
Na_2O	1.4113
NaOH	1.8204
Na_2CO_3	2.4113

$FeSO_4$, $7H_2O$

BaO	.5518
$Ba(OH)_2$	.6166
$BaCl_2$, $2H_2O$	.8789
CaO	.2018
$Ca(OH)_2$	.2665
$CaCO_3$	.3601
$CaH_2(CO_3)_2$	.5831
MgO	.1452
$Mg(OH)_2$	.2099
$MgCO_3$	.3034
$MgH_2(CO_3)_2$	.5252
Na_2O	.2234
NaOH	.2881
Na_2CO_3	.3817
$NaHCO_3$	.6047
NaF	.3025
Na_3PO_4, $12H_2O$	.9117

MgO

$Al_2(SO_4)_3$	2.8277
$Al_2(SO_4)_3$, $18H_2O$	5.5036
CO_2 (as monocarbonate)	1.0901
$CuSO_4$	3.9558
$CuSO_4$, $5H_2O$	6.1858
$FeSO_4$	3.7651
$FeSO_4$, $7H_2O$	6.8870
HCl	1.8062
SO_2	1.9838
H_2SO_4	2.4296

Incompatible Equivalents—Continued

$Mg(OH)_2$

Substance	Factor
$Al_2(SO_4)_3$	1.9555
$Al_2(SO_4)_3$, $18H_2O$	3.8061
$CuSO_4$	2.7357
$CuSO_4$, $5H_2O$	4.2779
Fe_2SO_4	2.6038
$FeSO_4$, $7H_2O$	4.7628
CO_2 (as monocarbonate)	.7539
HCl	1.2491
SO_3	1.3718
H_2SO_4	1.6802

$MgCO_3$

$Al_2(SO_4)_3$	1.3528
$Al_2(SO_4)_3$, $18H_2O$	2.6330
CO_2 (as Bicarbonate)	.5215
$CuSO_4$	1.8926
$CuSO_4$, $5H_2O$	2.9594
$FeSO_4$	1.8013
$FeSO_4$, $7H_2O$	3.2949
HCl	.8641
SO_3	.9490
H_2SO_4	1.1623

$MgH_2(CO_3)_2$

$Al_2(SO_4)_3$	.7797
$Al_2(SO_4)_3$, $18H_2O$	1.5176
$CuSO_4$	1.0908
$CuSO_4$, $5H_2O$	1.7057
HCl	.4980
$FeSO_4$	1.0382
$FeSO_4$, $7H_2O$	1.8991
SO_3	.5470
H_2SO_4	.6699

$MgCl_2$

BaO	1.6103
$Ba(OH)_2$	1.7992
CaO	.5839
$Ca(OH)_2$	.7778
Na_2O	.6519
NaOH	.8408
Na_2CO_3	1.1137

$MgSO_4$

BaO	1.2738
$Ba(OH)_2$	1.4233
CaO	.4658
$Ca(OH)_2$	.6153
Na_2O	.5156
NaOH	.6651
Na_2CO_3	.8807

Na_2O

Substance	Factor
$Al_2(SO_4)_3$	1.8377
$Al_2(SO_4)_3$, $18H_2O$	3.5769
$BaCl_2$	3.3542
$BaCl_2$, $2H_2O$	3.9339
CO_2	.7088
$CaH_2(CO_3)_2$	2.6103
$CuSO_4$	2.5710
$CuSO_4$, $5H_2O$	4.0202
HCl	1.1739
$FeSO_4$	2.4470
$FeSO_4$, $7H_2O$	4.4760
$MgCO_3$	1.3584
$MgH_2(CO_3)_2$	1.1784
$MgCl_2$	1.5339
$MgSO_4$	1.9391
SO_3	1.2892
H_2SO_4	1.5790

NaOH

$Al_2(SO_4)_3$	1.4246
$Al_2(SO_4)_3$, $18H_2O$	2.7731
$BaCl_2$	2.6004
$BaCl_2$, $2H_2O$	3.0499
CO_2	.5493
$CaH_2(CO_3)_2$	2.0237
$CuSO_4$	1.9932
$CuSO_4$, $5H_2O$	3.1168
HCl	.9101
$FeSO_4$	1.8971
$FeSO_4$, $7H_2O$	3.4701
$MgCO_3$	1.0531
$MgH_2(CO_3)_2$	.9138
$MgCl_2$	1.1892
$MgSO_4$	1.5033
SO_3	.9995
H_2SO_4	1.2242

Na_2CO_3

$Al_2(SO_4)_3$	1.0756
$Al_2(SO_4)_3$, $18H_2O$	2.0935
BaO	1.4458
$Ba(OH)_2$	1.6154
$BaCl_2$	1.9632
$BaCl_2$, $2H_2O$	2.3025
CO_2	.4147
$CaCl_2$	1.0461
$CaSO_4$	1.2833
$CuSO_4$	1.5048
$CuSO_4$, $5H_2O$	2.3530
HCl	.6870
$FeSO_4$	1.4322
$FeSO_4$, $7H_2O$	2.6197
SO_3	.7545
H_2SO_4	.9242

Incompatible Equivalents—Concluded

SO_3		H_2SO_4	
Substance	Factor	Substance	Factor
BaO	1.9160	BaO	1.5643
$Ba(OH)_2$	2.1408	$Ba(OH)_2$	1.7479
$BaCl_2$	2.6017	$BaCl_2$	2.1242
$BaCl_2, 2H_2O$	3.0514	$BaCl_2, 2H_2O$	2.4913
CaO	.7007	CaO	.5720
$Ca(OH)_2$	.9255	$Ca(OH)_2$	.7556
$CaCO_3$	1.2503	$CaCO_3$	1.0208
$CaH_2(CO_3)_2$	2.0247	$CaH_2(CO_3)_2$	1.6530
MgO	.5041	MgO	.4115
$Mg(OH)_2$	.7289	$Mg(OH)_2$	.5951
$MgCO_3$	1.0537	$MgCO_3$	.8602
$MgH_2(CO_3)_2$	1.8281	$MgH_2(CO_3)_2$	1.4925
Na_2O	.7756	Na_2O	.6332
NaOH	1.0004	NaOH	.8168
Na_2CO_3	1.3252	Na_2CO_3	1.0809
$NaHCO_3$	2.0976	$NaHCO_3$	1.7142

Amount of substances required to treat					Forming substances which remain in solution	
One Part of	Na_2O	NaOH	Na_2CO_3	$Na_2CO_3, 10H_2O$	Substance	Amount
$Al_2(SO_4)_3$	.5441	.7018	.9296	2.5068	Na_2SO_4	1.2456
$Al_2(SO_4)_3, 18H_2O$	.2795	.3606	.4776	1.2880	Na_2SO_4	.6399
$BaCl_2$	.2981	.3845	.5093	1.3735	NaCl	.5616
$BaCl_2, 2H_2O$	.2541	.3278	.4343	1.1711	NaCl	.4789
$CaH_2(CO_3)_2$	.3830	.4941			Na_2CO_3	.6545
$CaCl_2$	.5594	.7216	.9558		NaCl	1.0539
$CaSO_4$	.4560	.5882	.7792		Na_2SO_4	1.0438
$CuSO_4$	.3889	.5016	.6645	1.7919	Na_2SO_4	.8903
$CuSO_4, 5H_2O$	.2487	.3208	.4289	1.1459	Na_2SO_4	.5694
CO_2	1.4113	1.8204	2.4113	6.5022	Na_2CO_3	2.4113
$FeSO_4$	.4086	.5271	.6982	1.8827	Na_2SO_4	.9355
$FeSO_4, 7H_2O$	.2234	.2881	.3817	1.0292	Na_2SO_4	.5114
HCl	.8518	1.0987	1.4554	3.9245	NaCl	1.6049
$MgCO_3$	.7361	.9495			Na_2CO_3	1.2577
$MgH_2(SO_3)_2$	.8485	1.0945			Na_2CO_3	1.4498
$MgCl_2$	.6519	.8408			NaCl	1.2282
$MgSO_4$	.5156	.6651			Na_2SO_4	1.1805
SO_3	.7756	1.0004	1.3252	3.5735	Na_2SO_4	1.7756
H_2SO_4	.6332	.8168	1.0809	2.9176	Na_2SO_4	1.4497

The Red Water Plague

Filtration has proven a boon to mankind. Its value is large and unquestionable. However, some ills have followed its use at many different points. One of the most annoying and aggravating of these has been "The Red Water Plague." Some authorities have tried to ignore or belittle this very annoying evil, but we believe this to be a wrong policy. "To know the dis-

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ease is half the cure." So with the plague of Red Water. In order to overcome it, we must know what it is, how it is produced, and what means may be employed to minimize or prevent it. By Red Water is meant a water carrying enough of the iron compounds to impart a red color. Where Red Water is found it is usually not a transient affair. If an unusual flow is created in a main by opening a street hydrant to flush a dead end, or where several hydrants are opened as in the case of a fire, this results usually in stirring up more or less sediment in the main and water drawn therefrom may be turbid or discolored, even with a red color, for a number of hours or even for a day or two. This is not what is known as Red Water.

Where the latter is found the water is not quite clear, or it may be quite turbid. This turbidity is of a red color and may be composed of very small particles which are readily carried by the water and which settle out rather slowly. If the case is an aggravated one, a certain amount of the turbidity will settle more quickly. The color is imparted by hydrated ferric oxide. An ideal water must, among other things, be clear, sparkling and free from turbidity or notable color. It must not stain linen or spot it. It must not stain laundry, bath or toilet fixtures. Red Water fails to meet these specifications. It frequently carries considerable turbidity or may become turbid on standing. It stains or spots linen. It stains or colors porcelain, enamel or marble fixtures, and the red color imparted proves difficult or even impossible to remove. If a water is treated with an excess of iron sulphate and an insufficiency of caustic lime, iron is left in solution. If sufficient oxygen be present to oxidize the iron compounds, the iron oxide so formed will manifest its presence by the color given the water, the depth of color depending on the amount of iron oxide present. As most waters contain enough oxygen to oxidize the iron sulphate, it follows that it is impractical to use an excess of iron sulphate for water purification purposes, because such practice would immediately attract the attention of the user and create complaint. This forms one of the safeguards to the public in the use of this process. It is impossible to use an excess of iron sulphate without every user knowing it is being done. It is not necessary to employ a chemist to find the excess. It unmistakably reveals its presence to every observer.

Some other coagulants may be used to such an excess as to cause the filtered water to carry appreciable quantities in solution without the public becoming aware of the fact or able to learn of it except by employing a chemist to analyze the water. With the American Steel & Wire Company's process any excess of coagulant reveals itself to every user.

In plants where the coagulant contains no iron it is evident that if

the filtered water, when it reaches the consumer, is red with iron oxide, the coagulant cannot be the direct cause of the Red Water, and to the layman it is not obvious that the process may be even indirectly responsible. This, however, may be conclusively proven and demonstrated. If the coagulant does not supply the iron which the water carries, it is apparent that the iron must be obtained from some other source, and no expert is required to point out that the mains and services of the distribution system must furnish the source of supply.

Destructive Effects

In various places where this Red Water has been prevalent, the life of house services and fixtures, particularly the hot water systems, bear eloquent testimony of this fact; the life of the services in these instances proving remarkably short.

Hot water boilers have had to be removed every year in some localities. Hot water pipes have lasted but little longer, and the cold water services have not endured as they should. It is not necessary to argue that the larger mains of the city must also have suffered. These evils prevail to a greater or lesser extent where Red Water is found. This causes the householder undue and unnecessary expense and must eventually shorten the life of the mains, thus causing the city a large and unnecessary expense.

Water Wasted

Where this evil prevails it causes a larger use of water than would otherwise be found. The user will ordinarily waste enough water to flush the house pipes in an effort to procure a water which is somewhat freer from color than is the case where the supply in the house pipes is drawn directly after it has stood several hours. Where meters are installed, such waste increases the size of the consumer's bill, and where they are not, the expense of the waste has to be borne by the water department.

Where a large and continuous flow occurs through a main, the results of this evil are not so plainly seen, due to the fact that the large volume of water passing tends to lessen the amount of iron oxide in a given volume of water passing. Where the water passes very slowly or not at all, the opportunity for the formation of the Red Water is most marked.

Cause

The cause of this Red Water Plague is well known. Its chief cause may be named in three words, viz., Free Carbonic Acid. Iron, when immersed in water containing alkaline compounds of lime or magnesia, and very small quantities of salt or oxygen, and void of free carbonic acid, rusts very slowly. A water of this type carrying free carbonic acid will, on the contrary, attack iron readily and cause it to rust quickly. Some iron will be rendered soluble and some will be carried in suspension as red oxide of iron. The soluble iron, when exposed to atmospheric pressure, will

precipitate out of solution as red oxide of iron. The depth of color of this Red Water will depend largely upon the amount of iron which it contains, and this, in turn, upon the amount of free carbonic acid in the water, and the opportunity afforded the water for becoming saturated with iron by a slow passage through the distribution system. If the water be heated, its corrosive action will be intensified. This is the reason why the hot water services deteriorate more rapidly than the cold services.

The Cure

A water containing from 3 to 6 p.p.m. of monocarbonate alkalinity will have no free carbonic acid and will not therefore cause rapid corrosion of iron pipes, nor produce a Red Water even in hot water systems. This is the normal quality of water produced by the American Steel & Wire Company's system, and Red Water is not therefore found where this method of purification is employed, if the method is properly handled. Where alum is employed as a coagulant the conditions are different. Most of our water supplies carry bicarbonate of lime and magnesia in notable quantities, and occasionally some free carbonic acid. If the water carries free carbonic acid it already possesses the power to cause rapid corrosion of iron piping, and to produce a Red Water, without any chemical treatment whatever. If such a water be treated with alum the quantity of free carbonic acid is increased. The water is rendered hard because of this increase of carbonic acid and the tendency to produce Red Water is augmented.

Reactions

If we refer to pages 115, 117 and 118, under "Reactions of the Calcium, Magnesium and Sodium Compounds," the following reactions will be found:

$3CaCO_3 + Al_2(SO_4)_3, 18H_2O = 3CaSO_4 + Al_2(OH)_6 + 3CO_2 + 15H_2O.$

$3CaH_2(CO_3)_2 + Al_2(SO_4)_3, 18H_2O = 3CaSO_4 + Al_2(OH)_6 + 6CO_2 + 18H_2O.$

$3MgCO_3 + Al_2(SO_4)_3, 18H_2O = 3MgSO_4 + Al_2(OH)_6 + 3CO_2 + 15H_2O.$

$3MgH_2(CO_3)_2 + Al_2(SO_4)_3, 18H_2O = 3MgSO_4 + Al_2(OH)_6 + 6CO_2 + 18H_2O.$

$3NaCO_3 + Al_2(SO_4)_3, 18H_2O = 3NaSO_4 + Al_2(OH)_6 + 3CO_2 + 15H_2O.$

$6NaHCO_3 + Al_2(SO_4)_3, 18H_2O = 3Na_2SO_4 + Al_2(OH)_6 + 6CO_2 + 18H_2O.$

From the preceding it is seen that whenever alum is used to decompose a carbonate of lime, magnesia or soda, carbonic acid is given off and will be retained in solution by the water as free carbonic acid. This will intensify the tendency to produce Red Water. If, however, this free carbonic acid is neutralized or a little better than neutralized, by the use of lime or soda, the tendency toward Red Water will be reduced, and if there be from 3 to 6 p.p.m. of monocarbonate alkalinity, Red Water will not result.

Hardness

We frequently hear the statement made that when water is treated with alum there is no increase in the total hardness, that the carbonates of lime or magnesia, or soda, are merely converted into sulphates and the hardness *in toto* is not affected by the treatment. This is an error. It is true that a part of the carbonate hardness is converted into sulphate hardness and the total of the sulphate and carbonate hardness remains unaltered, but the acid hardness is increased to the extent of the increase in the free carbonic acid, and this in turn is increased proportionally to the amount of alum used. It is not wise, therefore, to ridicule the washwoman who affirms that the water is harder when alum is used. One part of alum having a chemical formula of $Al_2(SO_4)_3$, $18H_2O$ will release .198 times as much carbonic acid from a monocarbonate alkalinity. It makes no difference whether the alkalinity is composed of the carbonates of lime, magnesia, or soda.

Very few natural waters carry more than one or two p.p.m. monocarbonate alkalinity, except for a few days each year. Some never have any monocarbonate alkalinity. Most of the alkalinity of natural supplies is bicarbonate, and from a bicarbonate alkalinity 1 part of alum will release .3961 times as much carbonic acid. Stating it differently, one grain of alum when applied to a gallon of water possessing a bicarbonate alkalinity releases .3961 grain per gallon or 6.77 p.p.m. of free carbonic acid.

Natural vs. Filtered Water

Even though the natural water will not produce a Red Water the filtered water under these conditions may do so. As each grain per gallon or part per million of carbonic acid present increases the hardness to 2.275 times, it follows that for each grain per gallon of alum employed the hardness will be increased .9 g.p.g. or 15.4 p.p.m. if all the carbonic acid so liberated is held in solution in the filtered water. Where all of the carbonic acid liberated is absorbed with caustic lime and a small amount of monocarbonate is left in the filtered water, Red Water is not found. If sulphate of iron were to be employed without using caustic lime to produce this monocarbonate alkalinity in the filtered water, it is probable that Red Water would result from its use, as it does from that of alum. While this may be so, Red Water is not found in cities employing this process.

When the Lorain, Ohio, filtration plant was put in service in 1897, Red Water began to be manifest in the outlying districts of the city several months after the filter started. This continued up to the time of the introduction of the iron sulphite process invented by Mr. W. H. Jewell. No Red Water was

found while this process was employed. Later on the American Steel & Wire Company's process was introduced and the city still remained free from complaint regarding Red Water. Still later, owing to mechanical difficulties which made it impossible to use the American Steel & Wire Company's process in the new plant without making some changes in the construction, the American Steel & Wire Company's process was replaced by the alum process, and within a few months Red Water began to be noticeable, and is still found whenever the alum process is used. If the arrangement of this plant permitted the use of lime to neutralize the free carbonic acid it is logical to assume the Red Water would again disappear and the hardness and odor would become less noticeable.

Odor and Taste

In some instances the odor and taste of the filtered water are not improved by filtration, and in others the filtered water is worse in these respects than the natural water. Aeration has been used in order to overcome the odor and improve the taste. By these means rather satisfactory results have been obtained at some points; at others it has been found impractical to use this method. The hydrated oxide of iron formed in the American Steel & Wire Company's process is a strong deodorant and water purified by the process is always improved in odor and taste. At some points the improvement is very noticeable. At times when such odors or tastes in the natural water obtain, a freer use of iron sulphate will still further tend to eliminate these objectionable properties.

Analysis Report Form, American Steel & Wire Co.

ENGINEERING BUREAU—WATER PURIFICATION

American Steel & Wire Company

CHEMICAL ANALYSIS AND REPORT ON WATER

Sample No. .....

Sent in by ..... Source of Sample .....

Taken at ..... Date of Sampling 191

Sample Received 191

Description of Container .....

G. P. G. = Grains per Gallon. 1 G. P. G. = 17.1 P. P. M. P. P. M. = Parts per Million.
1 P. P. M. = .0584 G. P. G.
1 P. P. M. = 8.34 lbs. per Million Gallons of Water.
1 G. P. G. = 143 lbs. per Million Gallons of Water.

Probable Combination	G.P.G.	P.P.M.
Calcium Hydrate, $Ca(OH)_2$, by titration		
And corresponding in Alkalinity and Hardness in terms of Calcium Mono-carbonate to		
Calcium Mono-carbonate, $CaCO_3$, by titration, Standard for Alkalinity and Hardness		
Calcium Bi-carbonate, $CaH_2(Co_3)_2$, reported in weight as Calcium Mono-carbonate, $CaCO_3$		
Magnesium Hydrate, $Mg(OH)_2$, by titration		
And corresponding in Alkalinity and Hardness in terms of Calcium Mono-carbonate to		
Magnesium Mono-carbonate, $MgCO_3$		
And corresponding in Alkalinity and Hardness in terms of Calcium Mono-carbonate to		
Magnesium Bi-carbonate, $MgH_2(CO_3)_2$, reported in weight as Magnesium Mono-carbonate		
And corresponding in Alkalinity and Hardness in terms of Calcium Mono-carbonate to		
Sodium Hydrate, NaOH, by titration		
And corresponding in Alkalinity, but not in Hardness, in terms of Calcium Mono-carbonate to		
Sodium Mono-carbonate, Na_2CO_3, by titration		
And corresponding in Alkalinity, but not in Hardness, in terms of Calcium Mono-carbonate to		
Sodium Bi-carbonate, $NaHCO_3$, reported in weight as Sodium Mono-carbonate		
And corresponding in Alkalinity, but not in Hardness, in terms of Calcium Mono-carbonate to		
Total Caustic Hardness, in terms of Calcium Mono-carbonate		
Total Fixed Alkali Caustics, in terms of Calcium Mono-carbonate		
Total Caustic Alkalinity, in terms of Calcium Mono-carbonate		
Total Mono-carbonate Hardness, in terms of Calcium Mono-carbonate		

CHEMICAL ANALYSIS AND REPORT ON WATER—Continued

Probable Combination	G.P.G.	P.P.M.
Total Fixed Alkali Mono-carbonates, in terms of Calcium Mono-carbonate		
Total Mono-carbonate Alkalinity, in terms of Calcium Mono-carbonate		
Total Fixed Alkali Carbonates, in terms of Calcium Mono-carbonate		
Total Fixed Alkali Bi-carbonates, in terms of Calcium Mono-carbonate		
Total Carbonate Hardness, in terms of Calcium Mono-carbonate		
Total Bi-carbonate Hardness, in terms of Calcium-Mono-carbonate		
Total Bi-carbonate Alkalinity, in terms of Calcium Mono-carbonate		
Total Alkalinity by Analysis, in terms of Calcium Mono-carbonate		
Total Alkalinity by Titration, in terms of Calcium Mono-carbonate		
Calcium Chloride, $CaCl_2$,		
And corresponding in Hardness in terms of Calcium Mono-carbonate to		
Calcium Sulphate, $CaSO_4$,		
And corresponding in Hardness in terms of Calcium Mono-carbonate to		
Magnesium Chloride, $MgCl_2$,		
And corresponding in Hardness in terms of Calcium Mono-carbonate to		
Magnesium Sulphate, $MgSO_4$,		
And corresponding in Hardness in terms of Calcium Mono-carbonate to		
Free Carbonic Acid, CO_2, by titration		
And corresponding in Hardness in terms of Calcium Mono-carbonate to		
Free Sulphuric Acid, H_2SO_4, by titration		
And corresponding in Hardness in terms of Calcium Mono-carbonate to		
Total Chloride Hardness in terms of Calcium Mono-carbonate		
Total Sulphate Hardness in terms of Calcium Mono-carbonate		
Total Sulpho-chloride Hardness in terms of Calcium Mono-carbonate		
Total Free Acid Hardness in terms of Calcium Mono-carbonate		
Total Hardness in terms of Calcium Mono-carbonate, by analysis		
Total Hardness in terms of Calcium Mono-carbonate, by titration		
Sodium Chloride, NaCl,		
Sodium Sulphate, Na_2SO_4,		
Iron Oxide, Fe_2O_3, and Aluminum Oxide, Al_2O_3, reported together		
Silica, or Silicon Dioxide, SiO_2		
Organic and Volatile Matter		
Total Solids by Analysis		
Undetermined		
Total Solids by Evaporation		

INCOMPATIBLES

Where certain chemical substances exist in solution as they do in water, certain other chemical compounds are incompatible and cannot exist in the same solution. The following tables will give the substances which are incompatible in a water analysis. In other words, if any one of the substances given at the head of the tables is found in a water analysis, the items in this analysis form, mentioned below, will not be found to be present:

Calcium Hydrate, $Ca(OH)_2$, incompatible to

Calcium Bi-carbonate, $CaH_2(CO_3)_2$,
Magnesium Bi-carbonate, $MgH_2(CO_3)_2$,
Sodium Bi-carbonate, $NaHCO_3$,
Total Fixed Alkali Bi-carbonates,
Total Bi-carbonate Hardness,
Total Bi-carbonate Alkalinity,
Magnesium Sulphate, $MgSO_4$,
Free Carbonate Acid, CO_2,
Free Sulphuric Acid, H_2SO_4,
Total Free Acid Hardness.

If calcium hydrate is present the hydrates of magnesium and sodium may likewise be present. If either of these be present none of the above named substances will be.

Calcium Bi-carbonate, $CaH_2(CO_3)_2$, incompatible to

Calcium Hydrate, $Ca(OH)_2$,
Magnesium Hydrate, $Mg(OH)_2$,
Sodium Hydrate, NaOH,
Total Caustic Hardness,
Total Fixed Alkali Caustics,
Total Caustic Alkalinity,
Free Sulphuric Acid, H_2SO_4,
Total Free Acid Hardness.

If the bi-carbonates of magnesium or sodium be present the remarks under calcium bi-carbonate apply with equal force.

Sodium Hydrate, NaOH, incompatible to

Calcium Bi-carbonate, $CaH_2(CO_3)_2$,
Magnesium Bi-carbonate, $MgH_2(CO_3)_2$,
Sodium Bi-carbonate, $NaHCO_3$,
Total Fixed Alkali Bi-carbonates,
Total Bi-carbonate Hardness,
Total Bi-carbonate Alkalinity,
Calcium Chloride, $CaCl_2$,
Calcium Sulphate, $CaSO_4$,
Magnesium Chloride, $MgCl_2$,
Magnesium Sulphate, $MgSO_4$,
Free Carbonic Acid, CO_2,
Free Sulphuric Acid, H_2SO_4,
Total Chloride Hardness,
Total Sulphate Hardness,
Total Sulpho-chloride Hardness,
Total Free Acid Hardness.

Free Sulphuric Acid, H_2SO_4, incompatible to

Calcium Hydrate, $Ca(OH)_2$,
Calcium Mono-carbonate, $CaCO_3$,
Calcium Bi-carbonate, $CaH_2(CO_3)_2$,
Magnesium Hydrate, $Mg(OH)_2$,
Magnesium Mono-carbonate, $MgCO_3$,
Magnesium Bi-carbonate, $MgH_2(CO_3)_2$,
Sodium Hydrate, NaOH,
Sodium Mono-carbonate, Na_2CO_3,
Sodium Hydrate, NaOH,
Sodium Mono-carbonate, Na_2CO_3,
Sodium Bi-carbonate, $NaHCO_3$,
Total Caustic Hardness,
Total Fixed Alkali Caustics,
Total Caustic Alkalinity,
Total Mono-carbonate Hardness,
Total Fixed Alkali Mono-carbonates,
Total Mono-carbonate Alkalinity,
Total Fixed Alkali Bi-carbonates,
Total Bi-carbonate Hardness,
Total Bi-carbonate Alkalinity,
Total Alkalinity by Analysis,
Total Alkalinity by Titration,

Calcium Mono-carbonate, $CaCO_3$, incompatible to

Free Carbonic Acid CO_2,
Free Sulphuric Acid, H_2SO_4,
Total Free Acid Hardness.

INCOMPATIBLES—Continued

If calcium mono-carbonate be present, either the hydrates of calcium, magnesium or sodium may be present in small quantity, but if either of these hydrates be present, bi-carbonates of these same substances cannot be present. If calcium mono-carbonate be present, the bi-carbonates of calcium, magnesium or sodium may be present, but if the bi-carbonate of either of these be present, no hydrates of either of these three substances can be present. If the mono-carbonates of magnesium or sodium are present, the remarks under calcium mono-carbonate apply with equal force.

Sodium Mono-carbonate, Na_2CO_3, incompatible to

Calcium Bi-carbonate, $CaH_2(CO_3)_2$,
Magnesium Bi-carbonate, $MgH_2(CO_3)_2$,
Total Caustic Hardness,
Total Bi-carbonate Hardness,
Calcium Chloride, $CaCl_2$,
Calcium Sulphate, $CaSO_4$,
Magnesium Chloride, $MgCl_2$,
Magnesium Sulphate, $MgSO_4$,
Free Carbonic Acid, CO_2,
Free Sulphuric Acid, H_2SO_4,
Total Chloride Hardness,
Total Sulphate Hardness,
Total Sulpho-chloride Hardness,
Total Free Acid Hardness.

Sodium Bi-carbonate, $NaHCO_3$, incompatible to

Calcium Hydrate, $Ca(OH)_2$,
Magnesium Hydrate, $Mg(OH)_2$,
Sodium Hydrate, NaOH,
Total Caustic Hardness,
Total Fixed Alkali Caustics,
Total Caustic Alkalinity,
Calcium Chloride, $CaCl_2$,
Calcium Sulphate, $CaSO_4$,
Magnesium Chloride. $MgCl_2$,
Magnesium Sulphate, $MgSO_4$,
Free Sulphuric Acid, H_2SO_4,
Total Chloride Hardness,
Total Sulphate Hardness,
Total Sulpho-chloride Hardness,
Total Free Acid Hardness.

Calcium Chloride, $CaCl_2$, Calcium Sulphate, $CaSO_4$, Magnesium Chloride, $MgCl_2$, and Magnesium Sulphate, $MgSO_4$, incompatible to

Sodium Hydrate, NaOH,
Sodium Mono-carbonate, Na_2CO_3,
Sodium Bi-carbonate, $NaHCO_3$,

Free Carbonic Acid, CO_2, incompatible to

Calcium Hydrate, $Ca(OH)_2$,
Calcium Mono-carbonate, $CaCO_3$
Magnesium Hydrate, Mg $(OH)_2$,
Magnesium Mono-carbonate, $MgCO_3$,
Sodium Hydrate, NaOH,
Sodium Mono-carbonate, Na_2CO_3,
Total Caustic Hardness,
Total Fixed Alkali Caustics,
Total Caustic Alkalinity,
Total Mono-carbonate Hardness,
Total Fixed Alkali Mono-carbonates,
Total Mono-carbonate Alkalinity.

Addenda:.....
.....
.....

GENERAL STATEMENT

The sample when received had a **Turbidity** of.....P. P. M., the **Color** of the **Turbidity** being of a.....shade. The dissolved **Color** after being filtered through a **Berkfeld Filter** was.....P. P. M. The **Odor** cold was.....and when hot.....
Additional Remarks.....
.....
.....

ALUM PROCESS

The sample required.....grains per gallon of **Alumina Sulphate** $Al_2(SO_4)_3$, **18** H_2O to effect a proper coagulation. When treated with this quantity of **Alum** the **Color** removal by filtration was.....per cent., the **Color** being reduced to .....P. P. M.....
.....
In order to reduce the **Color** below.....P. P. M. it was necessary to use .....grains per gallon of **Alum.** When so treated the **Color** was reduced from.....P. P. M. to.....P. P. M.

AMERICAN STEEL & WIRE CO.'S PROCESS

In order to effect a satisfactory coagulation with the **American Steel & Wire Co.'s Process,** the sample required.....grains per gallon of **Ferrous Sulphate,** $FeSO_4$, **7** H_2O and.....grains per gallon of **Caustic Lime, CaO.** When so treated the coagulation was entirely satisfactory and the **Color** removal by filtration was.....per cent., the **Color** being reduced to.....P. P. M.....
.....
In order to reduce the **Color** below.....P. P. M. it was necessary to use .....grains per gallon of **Ferrous Sulphate** and.....grains per gallon of **Caustic Lime.**
When so treated the **Color** was reduced from.....P. P. M. to..... P. P. M.

LIME AND SODA ASH PROCESS

By the use of Caustic Lime alone at the rate of.....grain per gallon the **Hardness** of this water was reduced from.....G. P. G. or..... P. P. M. to.....G. P. G. or.....P. P. M. This is the maximum softening action which can be brought about by the use of **Caustic Lime** unassisted. When treated with this quantity of **Caustic Lime** and.....grains per gallon of **Soda Ash,** Na_2CO_3, 58 per cent. **Sodium Oxide,** Na_2O, the **Hardness** was reduced to.....G. P. G. or.....P. P. M. With the above treatment the **Color** was reduced from.....P. P. M. to.....P. P. M. and the **Odor** was.....by filtration.
This water can be purified by either of the following processes, viz:.....
.....
If the water is to be purified by straight mechanical filtration the.....
.....
process is preferable. If softening is to be resorted to, in addition, the water should occupy at least .....minutes' time to pass through the mixing chamber after **Soda Ash** has been added and.....hours to pass through the sedimentation basins. After having passed through the sedimentation basins it will probably be advisable to use.....grains per gallon of .....in order to re-coagulate the water and assist in preventing after deposits on the sand beds of the filter and the mains and services of the distribution system.

Respectfully submitted,

AMERICAN STEEL & WIRE COMPANY,
ENGINEERING BUREAU—WATER PURIFICATION.

.....
Chief Engineer.

TABLES

One part of	is considered as equivalent both in **Alkalinity** and **Hardness** to the following quantities of $CaCO_3$.
$Ca(OH)_2$	1.350
$CaH_2(CO_3)_2$	.617
$Mg(OH)_2$	1.715
$MgCO_3$	1.186
$MgH_2(CO_3)_2$	.683

One part of $CaCO_3$ is considered as equivalent both in **Hardness** and **Alkalinity** to the following quantities of

$Ca(OH)_2$	.740
$CaH_2(CO_3)_2$	1.619
$Mg(OH)_2$	.583
$MgCO_3$	.842
$MgH_2(CO_3)_2$	1.462

One part of	is considered as equivalent in **Hardness** to the following quantities of $CaCO_3$.
$CaCl_2$	.901
$CaSO_4$	.735
$MgCl_2$	1.050
$MgSO_4$	.831
CO_2	2.275
H_2SO_4	1.020

But none of these produces an **Alkalinity** in water.

One part of $CaCO_3$ is considered as equivalent in **Hardness** to the following quantities of

$CaCl_2$	1.108
$CaSO_4$	1.360
$MgCl_2$	.951
$MgSO_4$	1.203
CO_2	.439
H_2SO_4	.979

But none of these produces an **Alkalinity** in water.

One part of	is considered as equivalent in **Alkalinity** to the following quantities of $CaCO_3$ but as producing no **Hardness** in water.
NaOH	1.249
Na_2CO_3	.943
$NaHCO_3$	.595

One part of $CaCO_3$ is considered as equivalent in **Alkalinity** to the following quantities of

NaOH	.800
Na_2CO_3	1.059
$NaHCO_3$	1.697

But none of these produces **Hardness** in water.

Some of the following substances may, if present in large quantities, impart an appreciable **Hardness** but no **Alkalinity.** Owing to the relatively small quantities usually present in potable waters they are not considered as producing either **Alkalinity** or **Hardness** in water.

NaCl.
Na_2SO_4.
Fe_2O_3.
Al_2O_3.
SiO_2.
Organic and Volatile Matters.

One part of **Calcium Mono-carbonate, $CaCO_3$,** will neutralize 2.219 parts of **Alumina Sulphate $Al_2(SO_4)_3$, 18 H_2O.**

One part of **Alumina Sulphate, $Al_2(SO_4)_3$, 18 H_2O** will neutralize .4506 part of **Calcium Mono-carbonate, $CaCO_3$.**

One part of **Calcium Mono-carbonate, $CaCO_3$,** will neutralize 2.7768 parts of **Ferrous Sulphate, $FeSO_4$, 7 H_2O.**

One part of **Ferrous Sulphate** will neutralize .3601 part of **Calcium Mono-carbonate, $CaCO_3$.**

EXPLANATION OF TERMS

Caustic Hardness. The **Hardness** due to hydrates of **Calcium** and **Magnesium.**

Fixed Alkali Caustics. The **Alkalinity** due to hydrates of **Sodium** and **Potassium.**

Caustic Alkalinity. The **Alkalinity** due to hydrates of **Calcium, Magnesium, Sodium** and **Potassium.**

Mono-carbonate Hardness. The **Hardness** due to **Mono-carbonates** of **Calcium** and **Magnesium.**

Fixed Alkali Mono-carbonates. The **Alkalinity** due to **Mono-carbonates** of **Sodium** and **Potassium.**

Mono-carbonate Alkalinity. The **Alkalinity** due to the **Mono-carbonates** of **Calcium, Magnesium, Sodium** and **Potassium.**

Fixed Alkali Carbonates. The **Alkalinity** due to the **Mono-carbonates** and **Bi-carbonates** of **Sodium** and **Potassium.**

Fixed Alkali Bi-carbonates. The **Alkalinity** due to the **Bi-carbonates** of **Sodium** and **Potassium.**

Total Carbonate Hardness. The **Hardness** due to the **Mono-carbonates** and **Bi-carbonates** of **Calcium** and **Magnesium.**

Bi-Carbonate Hardness. The **Hardness** due to the **Bi-Carbonates** of **Calcium** and **Magnesium.**

Bi-Carbonate Alkalinity. The **Alkalinity** due to the **Bi-Carbonates** of **Calcium, Magnesium, Sodium** and **Potassium.**

Alkalinity. The **Alkalinity** due to the **Hydrates, Mono-carbonates** and **Bi-Carbonates** of **Calcium, Magnesium, Sodium** and **Potassium.**

Alkalinity by Titration. The **Alkalinity** just referred to and obtained by titration with an acid solution of known strength, using an indicator to determine the end reaction.

Alkalinity by Analysis. The **Alkalinity** above referred to, but determined by **Analysis** rather than by **Titration.**

Chloride Hardness. The **Hardness** due to **Chlorides** of **Calcium** and **Magnesium** and also to **Free Hydrochloric Acid.**

Sulphate Hardness. The **Hardness** due to **Free Sulphuric Acid** and the **Sulphates** of **Calcium, Magnesium, Iron** and **Alumina.**

Sulpho-Chloride Hardness. The **Hardness** due to **Free Hydrochloric** and **Sulphuric Acids** and the **Sulphates** and **Chlorides** of **Calcium, Magnesium, Iron** and **Alumina.**

Free Acid Hardness. The **Hardness** due to **Free Hydrochloric, Sulphuric** and **Carbonic Acids.**

Hardness or Total Hardness. The **Hardness** due to all **Free Acids, Hydrates, Mono-carbonates, Bi-Carbonates, Chlorides,** and **Sulphates** of **Calcium, Magnesium, Iron** and **Alumina.**

Isometric of Tub Filters

Mechanical Agitation Water Wash

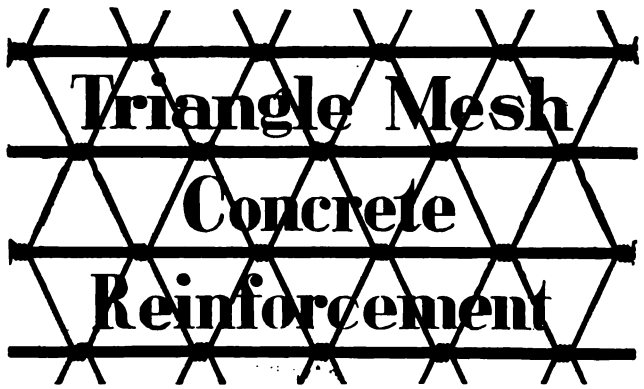
Air and Water Wash

Courtesy of P. P. Mfg. Co.

Minneapolis Chemical Controllers Earl Type

Filter Operating Table

American Steel & Wire Company's



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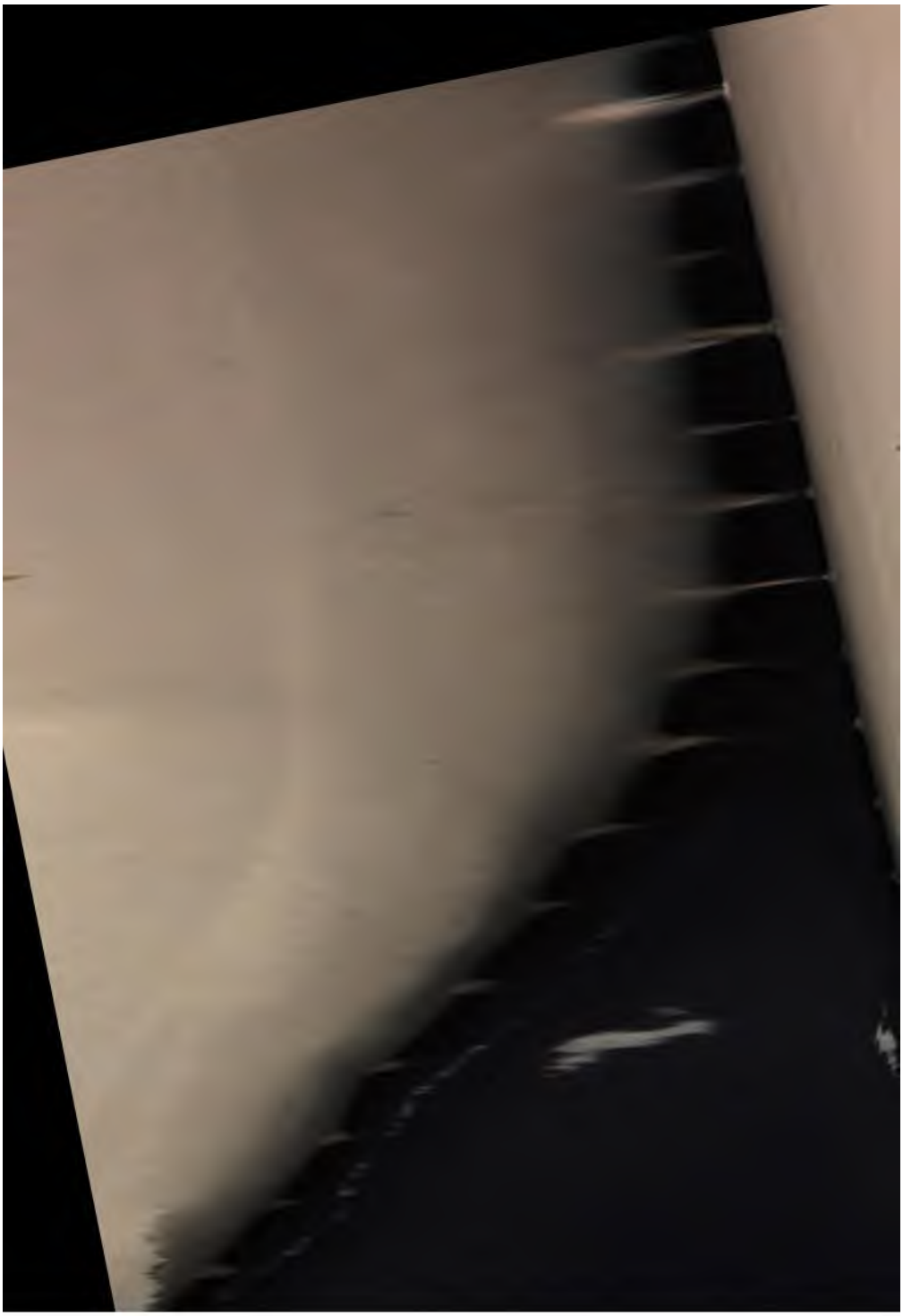
We will be glad to assist in the preparation of of plans and estimates for all work requiring concrete reinforcement.

NOV 2 8 1916

	Inch	Foot
Inch	1.0	0.083
Foot	12.0	1.0
Yard	36.0	3.0
Rod	198.0	16.5
Furlong	7,920.0	660.0
Mile	63,360.0	5,280.0
League	190,080.0	15,840.0
Millimeter	0.03937042	0.003
Centimeter	0.39370428	0.032
Decimeter	3.9370428	0.328
Meter	39.370428	3.280
Decameter	393.70428	32.808
Hectometer	3,937.0428	328.086
Kilometer	39,370.428	3,280.869
Myriameter	393,704.28	32,808.69

	Sq. Inch	Sq. Foo
Sq. Inch	1.0	0.(
Sq. Foot	144.0	1.(
Sq. Yard	1,296.0	9.
Sq. Rod	39,204.0	272.
Rood	1,568,160.0	10,890.(
Acre	6,272,640.0	43,560.(
Sq. Mile	4,014,489,600.0	27,878,400.(
Sq. Millimeter	0.0015500	0.(
Sq. Centimeter	0.15500	0.(
Sq. Decimeter	15.500	0.
Sq. Meter or Centiare	1,550.0	10.
Sq. Decameter or Are	155,000.0	1,076.
Hectare	15,500,000.0	107,638.
Sq. Kilometer	1,550,000,000.0	10,763,888.
Sq. Myriameter	155,000,000,000.0	1,076,388,888.(

	Cu. Inch	Cu. Foot	C
Cu. Inch	1.0	0.0005787	0.
Cu. Foot	1,728.0	1.0	0.
Cu. Yard	46,656.0	27.0	1.
Cu. Millimeter or Milligram	0.0000610234	0.0000000353	0.
Milliliter or Cu. Centimeter or Gram	0.0610234	0.0000353	0.
Centiliter or Decagram	0.610234	0.000353	0.
Deciliter or Hectogram	6.10234	0.00353	0.
Liter or Cu. Decimeter or Kilogram	61.0234	0.035315	0.
Decaliter or Centistere or Myriogram	610.234	0.35315	0.
Hectoliter or Decistere or Quintal	6,102.34	3.5315	0.
Kiloliter or Cu. Meter or Stere or Millier or Tonne	61,023.4	35.315	1.
Myrioliter or Decastere or Decatonne	610,234.0	353.15	13.
Grain (fluid)	0.003994	0.0000023107	0.
Ounce (fluid) avoirdupois	1.8046875	0.0010443	0.
Pound (fluid) avoirdupois	27.681246	0.01601924	0.
Gill	7.21875	0.004177	0.
Pint	28.875	0.01671	0.
Quart	57.750	0.03342	0.
Gallon	231.0	0.13368	0.
Wine Barrel	7,276.5	4.21093	
Oil Barrel	12,012.0	6.95512	
Hogshead	14,553.0	8.42186	



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